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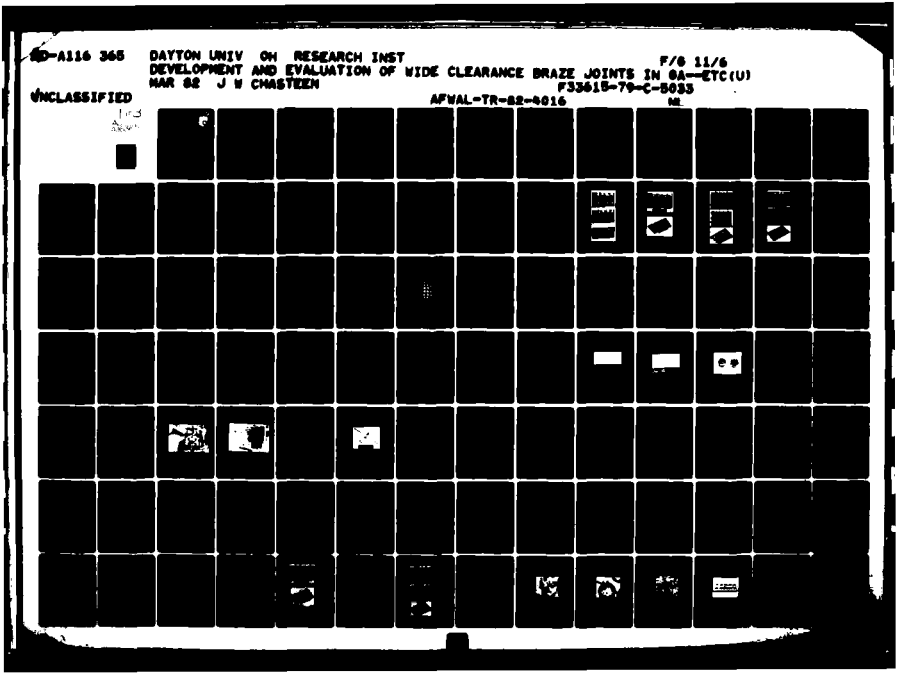

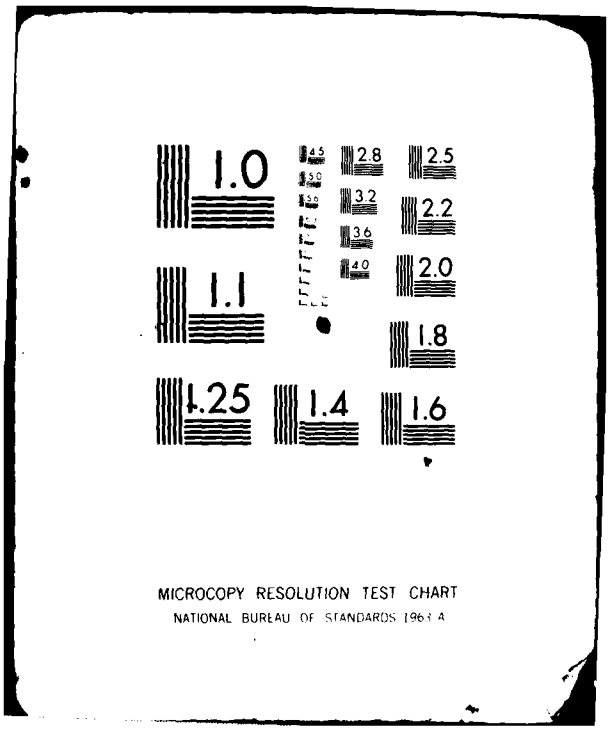
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AFWAL-TR-82-4016

DEVELOPMENT AND EVALUATION OF WIDE CLEARANCE BRAZE JOINTS IN GAMMA PRIME ALLOYS

J. W. Chasteen
University of Dayton
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Dayton, Ohio 45469

March 1982

Final Report for Period May 1, 1979 - May 1, 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The mechanical properties of wide clearance brazed butt joints in ALLOY 713C are reported. The joints vary in clearance from 10 to 70 mils and are made by a two step technique. The joint is first filled with a powdered metal which has a relatively high melting point and then a partial sintering step is performed. The joint is completed by filling the porous sinter powder with a nickel brazing alloy. Brazing filler metal

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20. powders and sinter filler metal powders were evaluated for their compatibility and brazing was improved by cleaning the base metal pieces by the fluorocarbon cleaning process (FCP).

For the right filler metal combination (René 80 with D 15 alloy) joint tensile strengths rivalled the base metal. There is no evidence of variations in strength with widths of clearance. In slow strain rate tests such as thermal fatigue and stress rupture, the results were widely scattered. The scattering is related to a plane of pores that develops at the upper faying surface of the joint during brazing. A case is made for the probability that the mechanical properties of such joints, when of high integrity, would rival and perhaps excel those of the ALLOY 713 base metal.

FOREWORD

This Final Technical Report covers the work performed under Contract No. F33615-79-C-5033 during the period May 1, 1979 to May 1, 1981. It is published for information and the conclusions herein are those of the contractor alone.

This contract, with the Welding and Joining Group of the University of Dayton Research Institute, was initiated under the title "Development and Evaluation of Wide Clearance Braze Joints in Gamma Prime Alloys." The work is being administered under the technical direction of Dr. G. E. Metzger of the Air Force Materials Laboratory, Metals and Ceramics Division, Wright-Patterson Air Force Base, Ohio.

The program is being directed by Dr. A. E. Ray, Project Supervisor, Metals and Ceramics Division. The principal investigator is Dr. J. W. Chasteen of the Welding and Joining Group.

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SECTION 1
INTRODUCTION

The high cost of aircraft gas turbine engine components has resulted in high interest in the repair of such components which have been damaged in service. Because of the very high cost and high damage frequency of components from the turbine section, the interest in repair of these components is especially pronounced. These high service temperature components are, however, quite often cast from nickel base superalloys which contain significant amounts of aluminum and/or titanium. These latter two elements, while imparting good high temperature mechanical properties to the superalloy by causing the precipitation of a coherent gamma prime phase, also cause somewhat severe problems in the weld or braze repair of service damaged components that are made from them.

The potential for conventional weld repair of γ'-type* engine components is compromised because of the necessity, in conventional welding, to melt the base metal at the joint. Imposed thermal stresses from welding, along with the normally uncontrolled dissolution and post-weld re-precipitation of the γ' phase results in post-weld cracking along the welded joints. The attraction of welding is also diminished by the fact that some crack defects are not accessible for weld repair. Furthermore, dirty and porous welds often result because of the inability to adequately clean the cracks. The cracks are difficult to clean because, as they form in service from thermally induced tensile stress fatigue, their surfaces become covered with oxides (and sulfides) of the aluminum and titanium used to strengthen the alloys. These oxides are among the most thermodynamically stable compounds, and until recently could not be removed from the

*Components which are made from gamma prime hardened alloys will be referred to as γ'-type.

damaged components in a nondestructive way. Recent advances at UDRI with the Fluorocarbon Cleaning Process (the FCP) have made it possible to clean the surfaces of the service damaged γ'-type components. Because the FCP is a gaseous process, it also cleans crack surfaces, and this opens a way to repair the very costly parts.

Since the alloys contain aluminum and titanium, post-weld cracking still discourages weld repair even though all surfaces and cracks are rendered oxide and sulfide free. With the advent of the FCP, however, braze repair is now feasible. It must be demonstrated however that the reliability of braze repaired parts is acceptable and that their service life is sufficient to be cost competitive with new parts. Since the service damaged parts are marked by thermal fatigue cracks, their braze repair differs from conventional brazing in three significant aspects: firstly, in service, the brazed joint will be loaded in tension rather than shear; secondly, the welding engineer has little freedom in establishing the brazing design and procedure to meet the service requirements of the brazed joints; and thirdly, and pointedly for the work reported here, wider joint clearances, up to 60 mils (1.5 mm), than are usual in conventional brazing, are often encountered in gas turbine engine component repair.

The investigation that is reported here was directed at two specific aspects that are indigenous to braze repair of service damaged, hot stage, gas turbine engine components. The investigation was directed to wide clearance brazed joints followed by a determination of their mechanical properties in tensile loading. Published information of this type is sparse and wide of the mark. A similar investigation for solid solution superalloys was conducted by Chasteen and Metzger[1]; the results were published in 1979.

SECTION 2
GENERAL PROCEDURE AND MATERIALS SELECTION

Because the purpose was to measure tensile properties of brazed joints, butt joints were made the objective of the investigation.

2.1 PROCEDURE

The approach selected for the brazing of wide clearance butt joints was to first sinter a nickel base alloy of high melting point (called the sinter filler metal) in powder form in the joint. This sintering is done lightly and results in a porous but not friable metallic mass in the joint. The sinter step is followed with filling of the powder interstices by brazing with a nickel base filler metal (called the braze filler metal) to complete the joint. The joint properties determined were tensile strength at room and elevated temperature, selected stress rupture life evaluation, and thermal fatigue life.

Before brazed butt joints could be made however, it was first necessary to determine which γ'-type superalloys could be brazed with which nickel brazes after FCP cleaning. It was also necessary to determine (at least among a judiciously chosen selection) which sinter filler metal candidates are compatible with which braze filler metals.

The sinter filler metal-braze filler metal-base metal compatibilities, the mechanical tensile properties measurements, and finally butt joint characterizations constitute the first, second, and final phases of the investigation.

2.2 MATERIALS

It is of course impractical to include all possible materials in any investigation of this scope or even to thoroughly evaluate those chosen. In the conduct of this effort there were three specific groups of materials; they

were: (1) the base metals, (2) the braze sinter metals, and (3) the braze filler metals. Considerable thought was given to the choice of these materials and every effort was made to choose materials that were representative of metallurgically generic groups. Also, the materials when chosen were only cursorily examined, and the results reported here should be taken in that sense.

2.2.1 The Base Metals

In choosing the γ'-type superalloys to be considered as base metals, a γ'-type alloy which enjoys broad application, is mildly alloyed, and is often employed in the wrought condition should be included. A second alloy which also enjoys broad application but is more highly alloyed and usually employed in the cast state should also be chosen. A third alloy which is rather highly alloyed and currently enjoys only limited application (latest generation of γ'-type alloys) would round out the grouping. These three alloys, when chosen for their generic qualities as well as the qualities stated above, would provide sound information, regarding nickel brazing, across the full spectrum of γ'-type superalloys. In view of the foregoing then, the base metal alloys that were chosen for compatibility investigations were Inconel X 750, ALLOY 713C, and Mar M246 alloy.

2.2.2 The Joint Making Materials

As was stated earlier, the joint clearances of interest in this study began at 10 mils (0.25 mm) and ranged to 60 mils (1.5 mm). Joints of these widths cannot be brazed in the conventional manner (a braze filler metal would run out of the joint). Consequently, a braze sinter metal must be included in the joint. This situation results in there being two separate materials in each joint, a braze sinter metal and a braze filler metal. These must be compatible with one another, and each must be compatible with the base metal.

2.2.2.1 The Braze Sinter Metals

In choosing the joint making metals the selection was limited to nickel base powders. The materials selection was further confined to powders that are commercially available.

In choosing the braze sinter metals, three types were desirable. The three types were: (1) a metal that had γ' precipitation capability, (2) a metal that did not have γ' precipitation capability, and (3) a material that was known to be compatible with at least one of the braze filler metals. Accordingly, the braze sinter metals that were considered in this study were René 80, Nicrogap 108, and Hastelloy Alloy C, respectively. Nominal compositions of the braze sinter metals are listed in Table 1. The mesh sizes were -325, -140, and -140 to +325, respectively.

For more information on this topic see Addendum No. 1.

2.2.2.2 The Braze Filler Metals

Nickel brazing is usually accomplished somewhere in the range of 1900°F (1040°C) to 2200°F (1200°C), and the braze filler metals were chosen so that their brazing temperatures were representative of this range. The temperature range lends itself to division into three groups: low melting brazes (1900-2000°F), intermediate melting brazes (2000-2100°F), and high melting brazes (2100-2200°F). A widely used low melting braze is BNi2 (recommended brazing temperature 1950°F). At the outset of this program, the investigator was most experienced with Nicrobraz 200[1] (recommended brazing temperature 2065°F). A relatively new brazing alloy that enjoys considerable attention is AMI DF 3 (recommended brazing temperature 2200°F). These alloys thus were chosen to represent the low, intermediate, and high melting brazes, respectively.

TABLE 1

NOMINAL CHEMICAL COMPOSITIONS OF THE BRAZE SINTER METALS AND THE BRAZE FILLER METALS

Material*	Weight Percent of Elements (Balance Ni)							
	Cr	Fe	Co	W	Mo	Si	B	Other
Nicrogap 108	15	7	-	-	-	.75	.20	
Hastelloy C	17	6	-	5	19	-	-	
René 80	14	0.2	9.5	4	4	0.2	0.015	3 Al, 5 Ti
Nicrobraz 200	7	3	-	6	-	4.5	3.2	
AMI 4777 (BNi 2)	7	3	-	-	-	4.5	2.8	
AMI DF 3	21	-	21	-	-	-	2.9	3.5 Ta, .03 La
D 15	15.3	.5 max	10.3	.05 max	.05 max	-	2.3	3.5 Al, 3.4 Ta

*All materials have abbreviations and quick codes that are used throughout the text. They are:

Material	Abbreviation	Quick Code
Nicrogap 108	N 108	108
Hastelloy C	Hast C	C
René 80	R´ 80	80
Nicrobraz 200	N 200	200
AMI 4777 (BNi2)	BNi 2	BNi2
AMI DF 3	DF 3	DF3
D 15	D 15	D15

At this juncture it was noted that, although the braze sinter metals included at least one γ' former, the braze filler metals did not (see Table 1). Thus alloy D 15 was included as one of the braze filler metals so that the final group was BNi2, Nicrobraz 200, AMI DF 3, and Alloy D 15. Their compositions are listed in Table 1.

SECTION 3
SELECTION OF BASE METAL AND JOINT MAKING MATERIALS

As has been stated, four braze filler metals and three braze sinter metals were chosen for screening. The number of potential sinter-filler combinations then was twelve. The scope of the effort, however, would allow for only two joint making combinations and thus ten of the twelve had to be eliminated prior to beginning the preparation of joined specimens for mechanical properties measurements. Also, there were, at the outset, three potential base metals. Again the project scope demanded that only one of them be used for the mechanical properties measurements.

The one necessity in wide clearance joint brazing is that the braze filler metal must wet both the base metal and the braze sinter metal. Accordingly, Phase I of the overall effort was devoted to judiciously choosing the most promising base metal and two braze sinter metal-braze filler metal combinations by eliminating those base metals and sinter-filler combinations that were least attractive.

3.1 BASE METAL - BRAZE FILLER METAL COMPATIBILITIES

The degree to which a braze filler metal wets a base metal surface is highly dependent upon the base metal surface preparation* and the manner of testing. The compatibility

*It is also dependent upon atmosphere, brazing temperature, and brazing time but these parameters were fixed for this effort.

tests were conducted by use of T-joint wet and flow experiments wherein the base metals had various surface preparations.

3.1.1 Pre-Conditioning of the T-Joints

The T-joints were fabricated by tack welding the two members of the joint in such a manner as to have a zero clearance joint (see Addendum 1). All T-joint members were made of slices cut with an abrasive saw, except the Inconel X 750 which was furnished in sheet form. All slices were roughly dressed by a water cooled abrasive belt prior to weld tacking.

One T-joint was left in the as-mechanically buffed condition. Two more joints were oxidized in an air furnace for 16 hours at 1700°F (925°C) and then grit blasted. One joint from these latter two was FCP cleaned. Thus the surface conditions of these T-joints were (1) mechanically buffed, (2) oxidized and grit blasted, and (3) oxidized, grit blasted, and FCP cleaned.

There is one other type of surface that is of particular interest if the data found in this effort are to be germane to repair of gas turbine engine components. Many such components, though made of γ'-type alloys, are coated (usually with an aluminide type coating) to improve their resistance to the hot corrosive gases of the engine. When such parts suffer service damage, it is necessary to clean them prior to braze repair. Furthermore, it is an idiosyncrasy of the FCP that the primary cleaning gas, a fluorocarbon, reacts unfavorably with the high aluminum containing coating and often leaves undesirable soot in the cracks. To avoid such an outcome, the damaged component must be first stripped of its protective coating and then FCP cleaned. A question naturally arises as to whether such surfaces are brazable.

Accordingly, a fourth T-joint was made and its surfaces mechanically buffed. They were then coated with Alpak coating. The coating was then thermally set followed by

the coating being stripped and the T-joints FCP cleaned. Thus a fourth surface condition was provided, namely, coated, stripped, and FCP cleaned.

3.1.2 Brazing the T-Joints

Three brazing parameters were the same for all joints, i.e., they were all vacuum furnace brazed in a vacuum of approximately 10^{-5} torr, held at the brazing temperature for 30 min, and had the filler metal powders secured with Nicrobraz 500 cement. The brazing temperature used was that recommended by the filler metal powder supplier and was never varied. BNi2 was brazed at 1950°F (1065°C), the Nicrobraz 200 at 2065°F (1130°C), and AMI DF 3 along with D 15 was brazed at 2200°F (1200°C).

The T-joints were prepared for brazing by mixing the filler metal powder with sufficient cement to allow molding. A small pile of filler metal was then placed at one end and on one side of each T-joint. The criteria for compatibility then were (1) length of braze run and opposite side filleting.

3.1.3 Results and Discussion of Base Metal-Filler Metal Brazes

The four surface preparation conditions are simulations of actual or potential brazing situations. In many fabrications of hot stage gas turbine engine components, brazing is used to assemble the component even though all or some of the materials are γ'-type alloys. This is accomplished by mechanically buffing the faying surfaces prior to brazing. In the case of service damaged, i.e., cracked parts, the crack is greatly exaggerated by grinding and then filled by a wide clearance brazing procedure.* This procedure provides freshly

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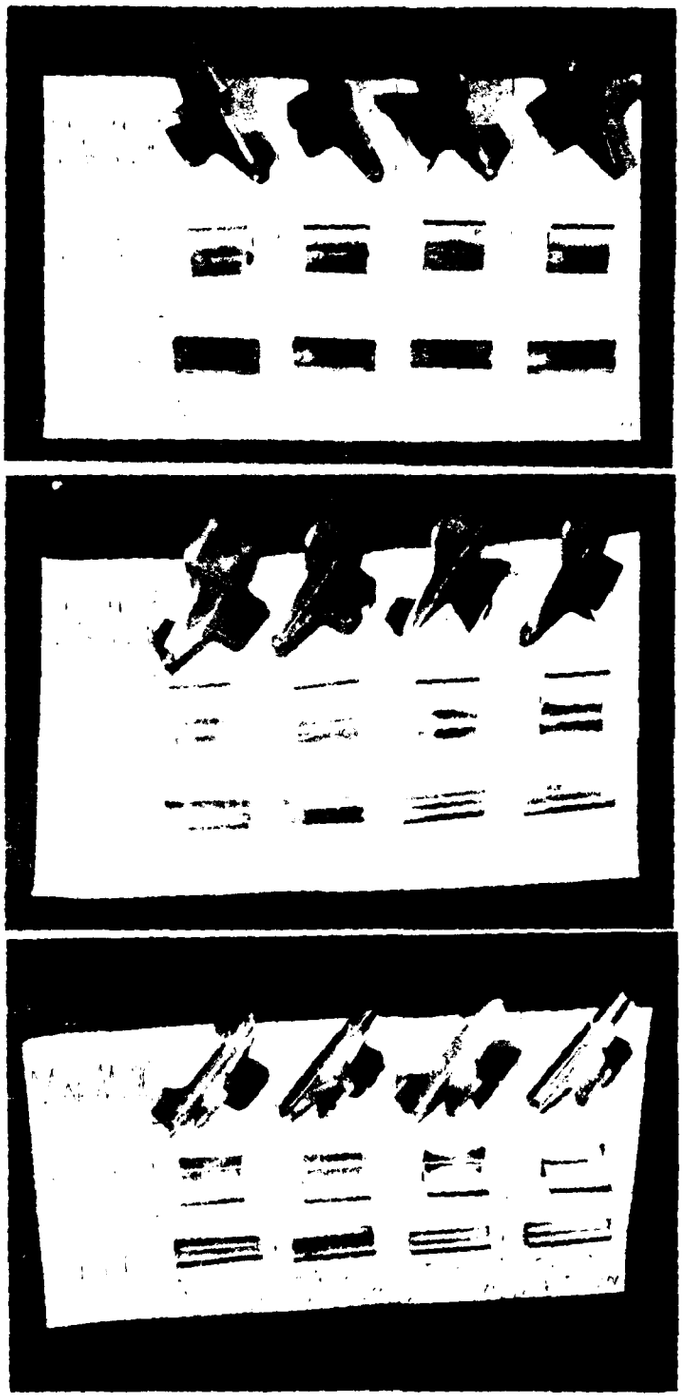
*It should be noted here that mixing of the sinter metal and the filler metal followed by a one step brazing cycle is perhaps a more widely applied technique than the sinter and braze procedure employed here.

ground faying surfaces at least so far as the defect is ground out. Therefore the as-mechanically buffed condition was meant to simulate these assembly and repair conditions.

When a gas turbine engine component has suffered crack damage in service and the crack is not ground out, some sort of surface cleaning is employed prior to any attempts to braze repair. The whole surface of such parts is coated with an oxide type film (perhaps sulfide as well); there is also often fuel residuals grime. A minimal surface preparation for such components might be acid pickling and/or grit blasting. Such techniques can provide surfaces similar to mechanically buffed surfaces but are unlikely to have affected the faying (crack) surfaces of narrow (<20 mil) cracks. The pre-oxidized and grit blasted T-bars are meant to simulate these minimal surface preparations where the zero clearance joints simulate narrow, service damage cracks.

The pre-oxidized, grit blasted, and FCP cleaned were meant to determine whether any increased wettability of both surfaces and narrow cracks was achieved through fluoro-carbon cleaning.

Figures 1, 2, 3, and 4 best summarize the results of the T-joint braze tests. Figure 1 shows the results for the mechanically buffed surfaces. Figure 1b shows that, for all alloys, all filler metals wet and ran the full length of the T-joints. Figure 1c shows that, for most alloys, most filler metals ran through the joint root and made at least a partial fillet on the opposite side; BNi2 on ALLOY 713C and Mar M246 as well as D 15 on Mar M246 are notable exceptions. Figure 2 shows the results for pre-oxidized and grit blasted surfaces. As expected, the photographs show that few braze filler metals ran the full length of the T-joint and that only one of them (DF 3 on Mar M246) ran through the joint root and made a fillet on the opposite side. Figure 3 shows that after FCP cleaning all of the braze filler metals ran the full length of the T-joints, ran through the joint root,

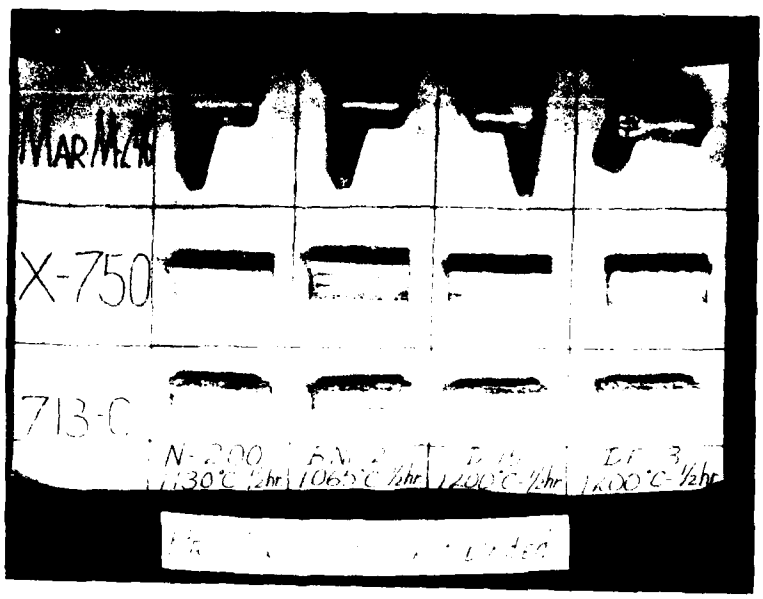


(a) prepared for brazing

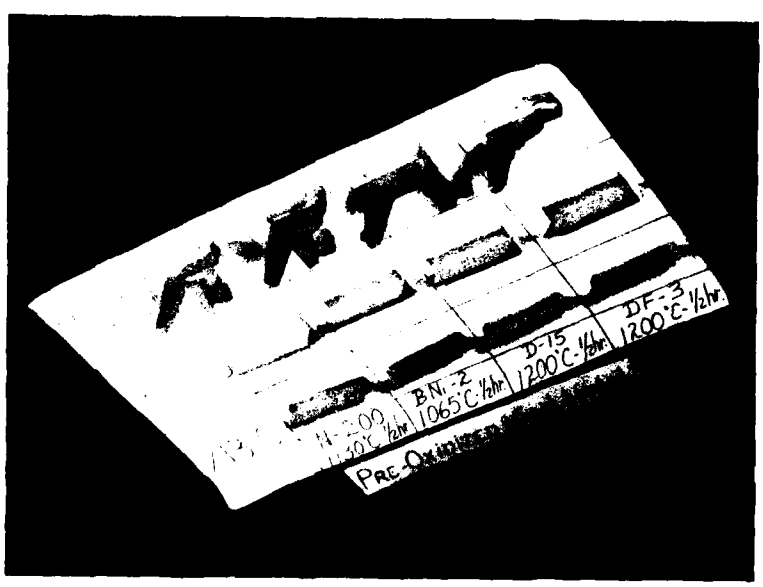
(b) brazed: filler metal side

(c) brazed: opposite filler metal side

Figure 1. T-joint braze tests for Mar M246, Inconel X 750, and ALLOY 713C with Nicrobraz 200, BNi 2, D 15, and AMI DF 3 brazing filler metals where the base metal surfaces are in the fresh cut and buffed condition.

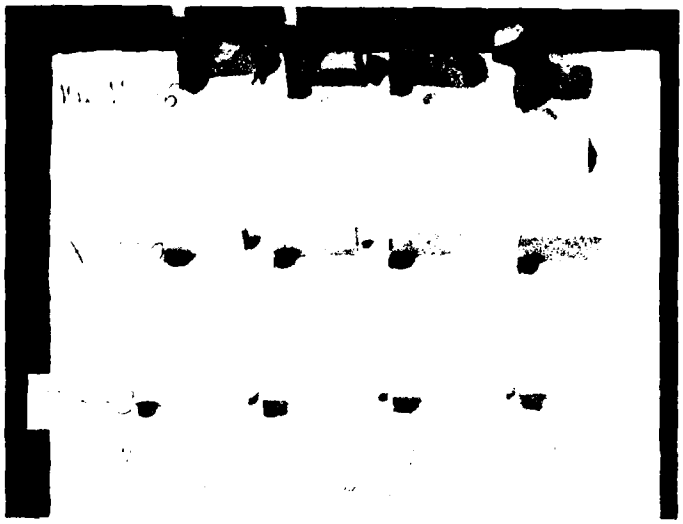


(a) brazed: filler metal side

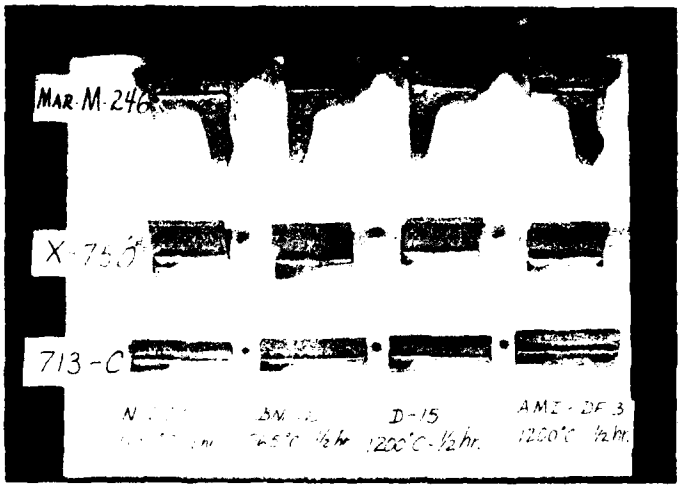


(b) brazed: opposite filler metal side

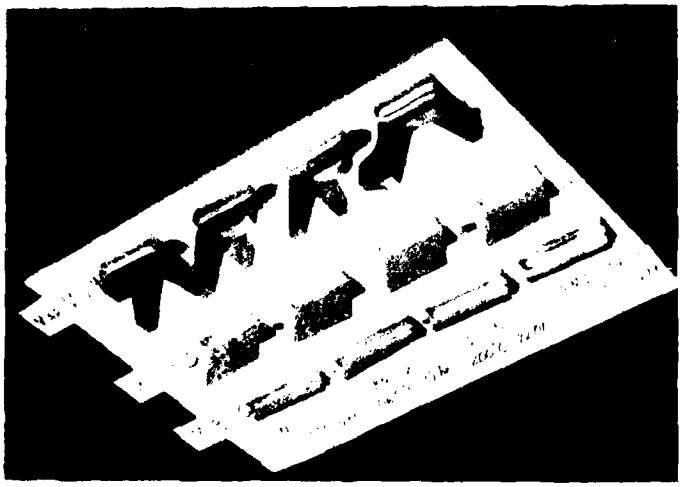
Figure 2. T-joint braze tests for Mar M246, Inconel X 750, and ALLOY 713C with Nicrobraz 200, BNi 2, D 15, and AMI DF 3 brazing filler metals where the base metal surfaces have been pre-oxidized and then grit blasted.



(a) prepared for brazing

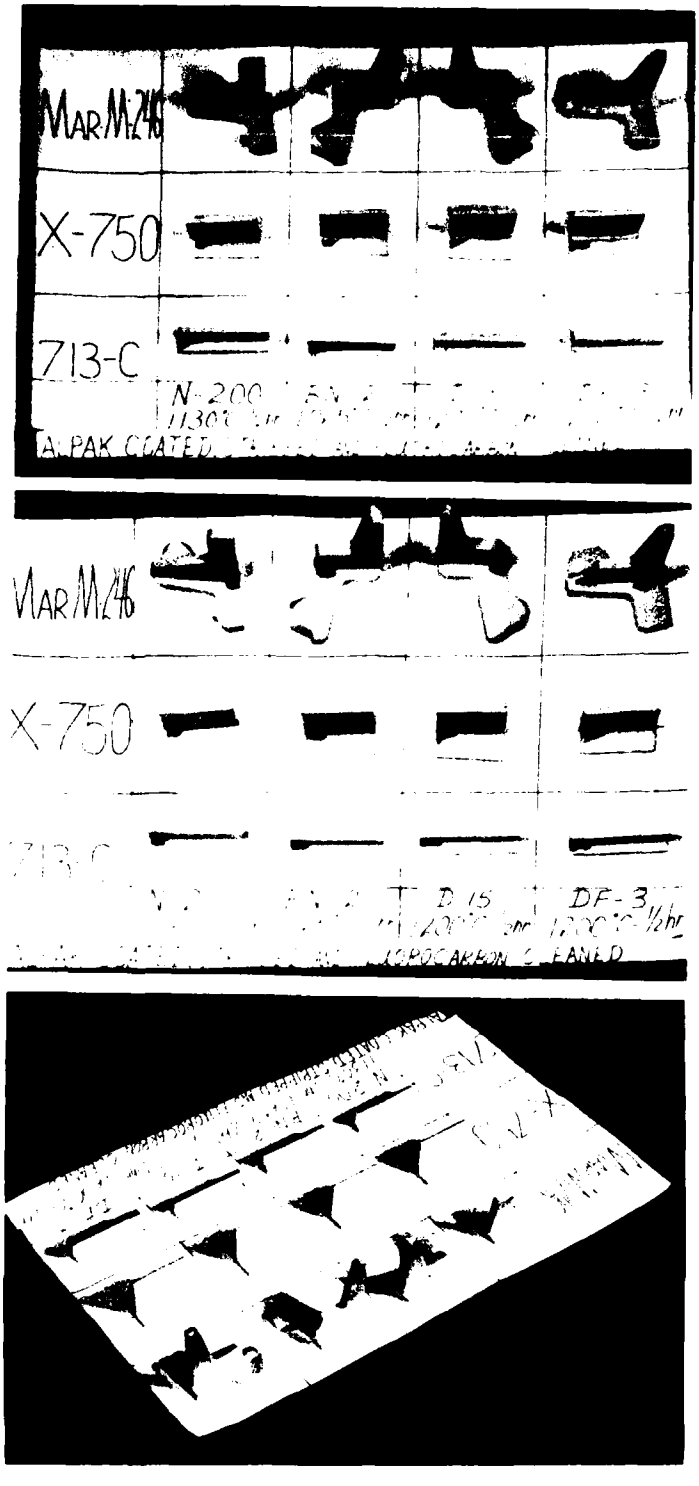


(b) brazed: filler metal side



(c) brazed: opposite filler metal side

Figure 3. T-joint braze tests for Mar M246, Inconel X 750, and ALLOY 713C with Nicrobraz 200, BNi 2, D 15, and AMI DF 3 brazing filler metals where the base metal surfaces have been pre-oxidized, grit blasted, and fluorocarbon cleaned.



(a) prepared for brazing

(b) brazed: filler metal side

(c) brazed: opposite filler metal side

Figure 4. T-joint braze tests for Mar M246, Inconel X 750, and ALLOY 713C with Nicrobraz 200, BNi 2, D 15, and AMI DF 3 brazing filler metals where the base metal surfaces have been coated, stripped, grit blasted, and fluorocarbon cleaned.

and made a creditable fillet on the opposite side. It is also noteworthy that the T-joint member surfaces adjacent to the joint were strongly wetted by most braze filler metals. It is further notable that, although not evident in the photographs, most of the tack welds cracked as might be expected; these cracks all filled with braze metal after FCP cleaning, but not in the case of other surface preparations.

Figures 4a, 4b, and 4c show that even when the alloys have been coated, stripped, and cleaned, the braze wettability of all alloys with all braze filler metals is excellent. For more details here see Addendum 2.

3.1.4 Conclusions on Base Metal-Braze Filler Metal Wettability

1. All of the candidate braze filler metals sufficiently wet any of the candidate base metals so long as the faying surfaces of base metal are adequately prepared.

2. When a γ'-type alloy component has been oxidized (or has been in service), grit blasting alone is not an adequate surface preparation.

3. As expected, mechanically buffing of faying surfaces is an adequate surface preparation technique, but it is apparently improved upon by fluorocarbon cleaning.

4. Fluorocarbon cleaning, after grit blasting, renders all surfaces, i.e., both exterior surfaces and the surfaces of any cracks or tight closures, readily wettable by all of the candidate braze filler metals and for all of the candidate base metals.

5. The Base Metal-Braze Filler Metal Wettability tests failed to eliminate any of the candidate base metals or braze filler metals.

6. Fluorocarbon cleaning subsequent to reasonable mechanical preparations is not only sufficient but apparently

necessary if excellent wetting of all surfaces (cracks and exterior) is to be relied upon. And this is true even for coated and stripped components.

3.2 BRAZE SINTER METAL-BRAZE FILLER METAL WETTABILITY

Because all of the candidate braze filler metals readily wet all candidate base metals after FCP cleaning, no joint making materials or candidate base metals can be eliminated by the results of the T-joint tests. Therefore, any eliminations must occur due to lack of wettability of the braze sinter metals by some braze filler metals. The next task was undertaken to ascertain these wettabilities.

3.2.1 The Sintered and Brazed Wafer Technique

In order to properly explain the wafer technique, it is first necessary to explain the intended eventual use of the wettability information. The end intent is to produce butt joints in the center of tensile test bars so that the mechanical properties of such joints can be ascertained. The method of producing such joints (which can be reproduced in gas turbine engine components assembly and repair) is to firstly cause a butt joint clearance of prescribed width to be filled by a braze sinter metal, secondly partially sinter that green assembly, and finally complete the joint by placing a feeder unit filled with a braze filler metal so that, at the brazing temperature, the filler metal can flow into the porous, partially sintered joint area, fill the pores and complete the joint. Thus the critical feature of braze sinter metal-braze filler metal compatibility is whether the filler metal will flow into and completely fill a volume of partially sintered braze sinter metal. In order to ascertain the degree of wetting and flow, the wafer technique was developed.

3.2.1.1 The Wafer Technique

In order to fill a joint with braze sinter metal the metal powder is mixed with a binder which makes the powder moldable. Such mixtures are used to form molded wafers in a teflon mold (see Figure 5 of Addendum 1). When the teflon mold is well polished, the dried wafers are easily stripped from it. Wafers thus produced were partially sintered by the following cycle: heat in vacuum to 500°F (260°C), proceed to 700°F (350°C) over the course of 1 hour, proceed further to 2065°F (1130°C) and hold for 1/2 hour. This cycle was employed for all pre-sintering during this effort.

At the beginning of the effort there was a question about the effects, if any, of different binders. It is known that water soluble binders are more forgiving than acetone/alcohol soluble binders insofar as time to complete the molding is concerned. Therefore and since little additional effort was required, all wafers in the study were made in duplicate; one wafer was made with Nicrobraz 500 cement (acetone/alcohol soluble) and the other was made with Nicrobraz 'S' cement (water soluble).

As stated earlier, there were three candidate braze sinter metal powders; all combinations of these with the two binders and the four candidate braze filler metals were investigated in the wafer study.

3.2.1.2 Volume, Density, Porosity, and Shrink

At each stage in the production of brazed wafers, where applicable the volume, density, percent porosity, and the percent shrink were measured. Because of contiguous porosity these properties could not be measured by water immersion and had to be measured by submersion in mercury. Since the wafers were all less dense than mercury,

a tungsten ballasting technique was used (for more detail see Addendum 1). The results of all such measurements are tabulated in Table 2.

3.2.1.2.1 Percent Shrink

This value is important for the sintered wafers and for the brazed wafers. It has a direct bearing on whether in making a joint or filling a crack for repair, the high temperature material will shrink away from a faying surface or fracture along the center line. Either of these eventualities will result in a plane of braze metal, without braze sinter metal particles, in a disadvantageous orientation. Table 2 shows that the shrink from green to sintered wafers in all cases of Nicrogap 108 makes this sinter metal unattractive. Perhaps the sintering temperature was too high and its adjustment would rectify the situation. Doing so, however, was outside the scope of this effort and this sinter metal fell back in the overall considerations because of the excessive shrink.

It may also be noted that high percentage shrink from green to sintered wafer cause suspicions that there may be localized compromises of the contiquous porosity. Such conditions would be expected to result in lack of braze metal fill at those locations. This condition must be avoided in joint making.

3.2.1.2.2 Volume and Density

These values have no direct consequence. They are used in calculating the more consequent values, shrink and porosity.

3.2.1.2.3 Porosity

The characteristic of porosity has significance at two stages of the wafer technique. It is of course significant for the brazed wafers where,

TABLE 2

PERTINENT WAFER DATA

							Brazed Wafers				
							Filler Metal	Weight of Filler Metal Applied (g)		Density ρ_B (g/cc)	Percent Shrink
							N 2 [illegible]	4.3	1.38	6.32	3.46
							BN1 2	4.6	1.24	7.28	-8.22
							DF 4	4.6	1.27	6.37	3.15
							D 15	3.4	1.27	7.45	5.23
							N 2 [illegible]	2.7	1.23	6.31	3.64
							BN1 2	2.6	1.18	7.72	-5.23
							DF 4	2.9	1.17	6.31	4.77
							D 1	2.6	1.14	6.12	4.35
							N 2 [illegible]	6.95	1.84	6.1	-3.7
							BN1 2	6.3	1.33	6.64	-6.7
							DF 4	6.1	1.72	6.43	2.9
							D 15	5.7	1.67	6.36	-2.2
							N 2 [illegible]	5.	1.69	6.2	-3.7
							BN1 2	4.4	2.11	7.6	-15.3
							DF 4	4.4	2.21	6.56	2.9
							D 15	4.3	1.68	7.04	-2.2
							N 2 [illegible]	5.8	1.73	7.2	-3.37
							BN1 2	4.7	2.34	7.64	-14.7
							DF 4	4.7	1.75	7.1	1.55
							D 1	4.7	1.59	7.34	-1.53
							N 2 [illegible]	5.8	1.7	7.4	-4.4
							BN1 2	4.9	2.46	7.28	-9.1
							DF 4	4.8	1.64	6.9	1.6
							D 1	4.7	1.4	7.34	1.2

*These data taken from half wafers.

ideally, it should be nonexistent but is tolerable up to about 10 percent of the volume. At the brazed wafer stage the porosity is assessed qualitatively by metallography. Porosity is also important at the sintered wafer stage because its extent dictates the amount of braze filler metal that is required to fill all of the pores. At the sintered stage the percent porosity must be known quantitatively.

The porosity of sintered wafers is assessed in the following manner:

1. Secure values for the density of mercury (ρ_{Hg}), the densities of the braze sinter metals as 100% dense (theoretical) (ρ_S^{Th}), and the densities of the braze filler metal (ρ_B^{Th}), see Addendum 1.

2. Weigh the tungsten ballast in air (W_B^a).

3. Weigh the tungsten ballast as submerged in mercury (W_B^{Hg}).

4. Weigh the sintered wafer in air (W_S).

5. Attach the wafer to the ballast and weigh the combination in air (W_{W+B}^a).

6. Weigh the combination as submerged in mercury (W_{W+B}^{Hg}).

The volume of a sintered wafer (V_s) is then given by

$$V_s = \frac{(W_{W+B}^a - W_{W+B}^{Hg}) - (W_B^a - W_B^{Hg})}{\rho_{Hg}} .$$

The pore volume (V_p) is then given by

$$V_p = V_s - W_S/\rho_S^{Th}$$

and the percent porosity is simply

$$\% \text{ porosity} = \frac{V_p}{V_s} \times 100 .$$

The proper amount of braze filler metal to just fill the pores is

$$W_{Br} = \rho_B {}^{Th}V_p$$

where W_{Br} is the weight of braze filler metal that should be applied to the wafer in order to fill all of the pores while preserving the volume of the wafer.

3.2.1.3 Brazing

When the wafers had been sintered, the requisite amount of braze filler metal to be applied to each was calculated by the above equation. The braze filler metal was then mixed with the same cement that was used to make the wafer and applied to the wafer as a small mound on the top side (reference: earth during brazing). Brazing was then accomplished in vacuum for 30 minutes at each braze filler metal's recommended brazing temperature (see 2.2.2.2). Qualitative visual results of the brazing may be seen in Figure 5.

Data from the ballasted mercury immersion measurements that were taken after brazing may also be found in Table 2. The high negative shrinks of some brazed wafers are, at first glance, alarming. They seem to indicate that the wafer has swollen upon brazing. Reference to Figure 5 for those wafers, however, quickly shows that the effect is usually due to lack of wetting with the result that the new volume is simply that of the partially unbrazed wafer plus the braze metal. Such a situation does of course eliminate that combination of materials from the joint making candidates. In some cases, the brazed wafers showed evidence of sinter metal melting, which indicate an excessively high brazing temperature. Wafers produced by use of lower brazing temperatures, however, proved to be unfilled and thus unacceptable (see Addendum 1).

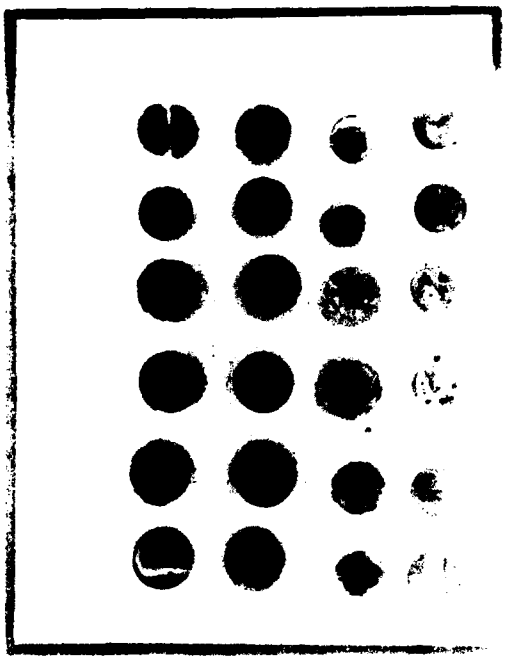


Figure 5. Brazed wafers resulting from all sinter filler metal combinations.

3.2.1.4 Metallography

Wafers from those braze sinter metal-braze filler metal combinations which could not be eliminated for obvious lack of wetting were sectioned and prepared for metallographic examination. These examinations resulted in (1) the Nicrobraz 500 cement being preferred, (2) the Nicrogap 108 braze sinter metal being all but eliminated from candidacy, but (3) leaving four, and perhaps six, viable joint making combinations.

3.3 SELECTION OF MATERIALS

At this juncture and with no more than cursory further investigations it was necessary to choose the base metal and the two joint making materials combinations that would be used for investigation of mechanical properties of brazed butt joints. Choice of base metal could be made but the choices of joint making materials required some further experimentation.

3.3.1 The Base Metal

It was not possible to choose among the candidate base metals on the basis of superior wettability because all of them could be made to wet excellently by all braze filler metals by application of FCP cleaning. Therefore, a base metal was chosen for its ready availability and its familiarity to the investigators. That alloy was ALLOY 713C. Thus ALLOY 713C became the base metal that was used exclusively in all further investigations.

3.3.2 Preliminary Test Specimens

The metallography of some of the wafer combinations was fetching even though there was evidence of incomplete fill. It was known from experience[1] that braze sinter metal-braze filler metal combinations that seemed marginal in wafers often produced excellent brazed butt joints. Thus six

candidate combinations were selected for further investigations. They were:

Braze Sinter Metal	Braze Filler Metal
Nicrogap 108	Nicrobraz 200
Nicrogap 108	BNi2
Hastelloy C	AMI DF 3
Hastelloy C	D 15
René 80	AMI DF 3
René 80	D 15

These combinations were then used to produce 15-mil joint clearance brazed butt joints in ALLOY 713C tensile test specimen blanks.* After the specimens were made, the joints were cut out, sectioned along their diameters and examined metallographically. This procedure completed the data gathering for choosing the joint making materials.

3.3.3 The Joint Making Materials

Because of what was judged to be less than optimal microstructures (multiphased matrix), all joints that contained Nicrogap 108 as a braze sinter metal were eliminated. The remaining four combinations were all viable regardless of the binder used. The final decision was made with an attitude of not duplicating either the braze sinter metal or the braze filler metal in the final joint making combinations. Accordingly, the joint making combinations that were used for the mechanical properties evaluations were:

Braze Sinter Metal	Braze Filler Metal	Quick Code
1. Hastelloy C	AMI DF 3	C/DF3
2. René 80	D 15	80/D15

*For complete details and discussion of the brazed butt joint making procedures and apparatus, see Addendum 2.

3.4 SUMMARY OF MATERIALS SELECTION

The foregoing was aimed at choosing joint making materials for mechanical properties determinations on wide clearance brazed butt joints produced by a two step method. It was necessary to choose one base metal, one powder binder, and two combinations of braze sinter metal and braze filler metal. The final choices were:

Base Metal: ALLOY 713C

Binder: Nicrobraz 500 Cement

Braze Sinter Metals: Hastelloy C and René 80

Braze Filler Metals: AMI DF 3 and D 15

Joint Making Combinations: Hastelloy C with AMI DF 3 and René 80 with D 15.

SECTION 4

MECHANICAL PROPERTIES OF WIDE CLEARANCE BRAZED BUTT JOINTS

The mechanical properties of brazed joints as applied to component repair are tensile strengths, stress rupture life, and thermal fatigue life. Consequently these were the mechanical properties that were evaluated. Some of the evaluation techniques were necessarily unusual and at least one was somewhat unique. All were revealing.

4.1 TENSILE PROPERTIES OF THE JOINT

Variation of the ultimate tensile strength with temperature is important in the design of components. Also important are variations of UTS with joint clearance and this property may itself vary with temperature. Thus the UTS - temperature - joint clearance variations were determined.

Since the test specimens were expected to fail in the butt joints and the joints are all narrow with respect to an approximate 1-inch gage length, the yield strengths of such specimens was adjudged meaningless or at least subject to nebulous interpretations. Percent elongation as a property suffers from the same malady, and therefore, neither yield strength nor elongation were measured.

4.1.1 UTS vs. Temperature (Fixed Joint Clearance)

In order to ascertain the variation of tensile strength of the brazed butt joints with temperature, the joint clearance was set at 15 mils. Tensile test specimen blanks were made, for each joint making combination, in duplicate for each testing temperature. The testing temperature range was room temperature to 1800°F (985°C) and

the specimen was in accordance with Figure 8 of ASTM E8-79 with a nominal diameter of 0.350 inches and the butt joint is in the center of the specimen. The specimens were tested in the as-brazed condition, and the tests were conducted at a constant crosshead speed of 0.05 inches per inch per minute. For more detail, see Addendum 3.

The tensile test data are listed in Tables 3 and 4. Also listed are the published[2] tensile strengths of ALLOY 713C for ease in comparison. The data are most easily seen graphically and are thus presented in Figure 6. As is readily seen, the René 80/D 15 joints compare favorably with the strengths of the base metal; indeed in some cases at elevated temperatures, the failures occurred in the base metal (see Addendum 3). The Hastelloy C/AMI DF 3 joint, however, proved inferior to the base metal and thus to the other joint making combination. Figure 7 depicts a comparison of strengths of butt joints where Hastelloy C was the braze sinter metal but the braze filler metals were AMI DF 3 with ALLOY 713C base metal and Nicrobraz 200 with Hastelloy X base metal. These data will be more fully examined in the Discussion.

4.1.2 UTS vs. Joint Clearance (For Fixed Temperatures)

It was necessary to ascertain any variations of tensile properties with joint clearance of the brazed butt joints. The tensile test results of variation with temperature indicated that the joint making combination René 80/D 15 is quite attractive while that of Hastelloy C/AMI DF 3 is no longer of interest because of the low tensile strength of such joints. Accordingly, it was decided that all remaining efforts of the program should be expended in elucidating

TABLE 3

TENSILE STRENGTH OF ALLOY 713C TEST BARS
WHICH HAD A 15 MIL BRAZED BUTT JOINT
IN THE CENTER OF THE TEST SECTION
(Hastelloy C/AMI DF 3)

Joint Material: -140 Hastelloy C
sinter metal with
AMI DF 3 filler metal

Testing Temperature (°F)	Tensile Strength (psi)	Tensile Strength of ALLOY 713C* (psi)
70	66,300 63,600	123,000
1000	60,700 74,600	125,600
1200	81,700 75,700	125,700
1400	66,300 65,400	136,000
1600	65,400 97,300	105,400
1800	47,300 37,800+	68,400

*See Reference 3.

+This failure appears to have initiated at a faying surface.

TABLE 4

TENSILE STRENGTH OF ALLOY 713C TEST BARS
WHICH HAD A 15 MIL BRAZED BUTT JOINT
IN THE CENTER OF THE TEST SECTION
(René 80/D 15)

Joint Material: -325 René 80 sinter metal brazed with D 15 filler metal

Testing Temperature (°F)	Tensile Strength (psi)	Tensile Strength of ALLOY 713C* (psi)
70	113,100 116,900	123,000
1000	124,100 79,900+	125,600
1200	126,000 122,200	125.700
1400	122,900 116,500	136,000
1600	110,300 130,500++	105,400
1800	76,100 64,700++	68,400

*See Reference 3.

+This sample had a single pore defect at the periphery of the test section.

++These samples failed in the base metal part of the test section.

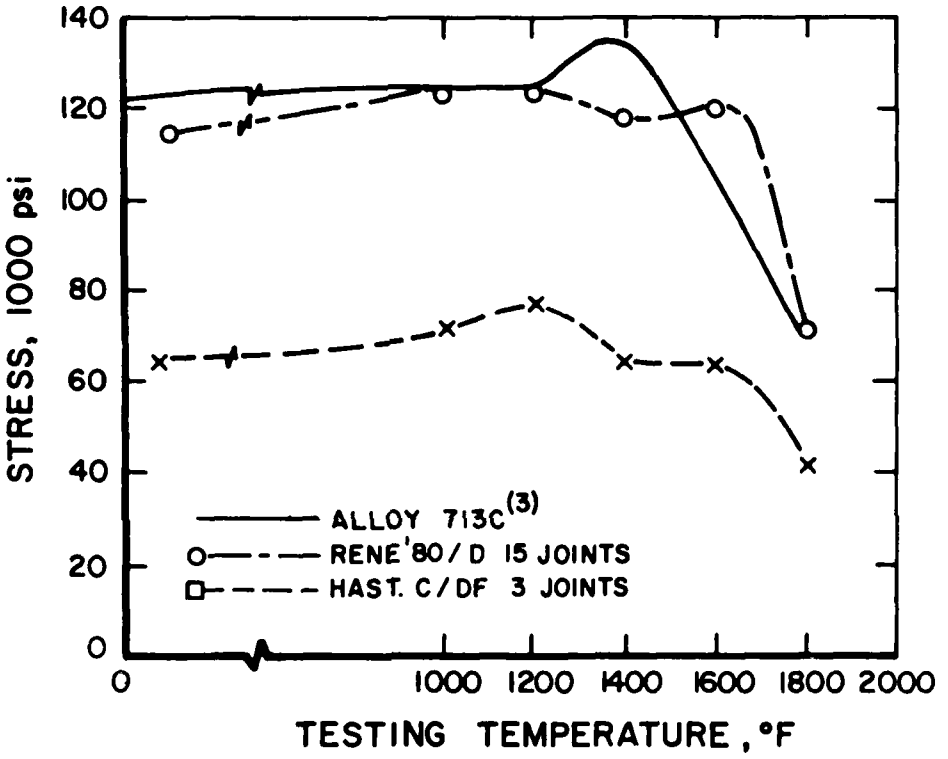


Figure 6. Tensile strength versus temperature for 15-mil butt brazed joints in ALLOY 713C.

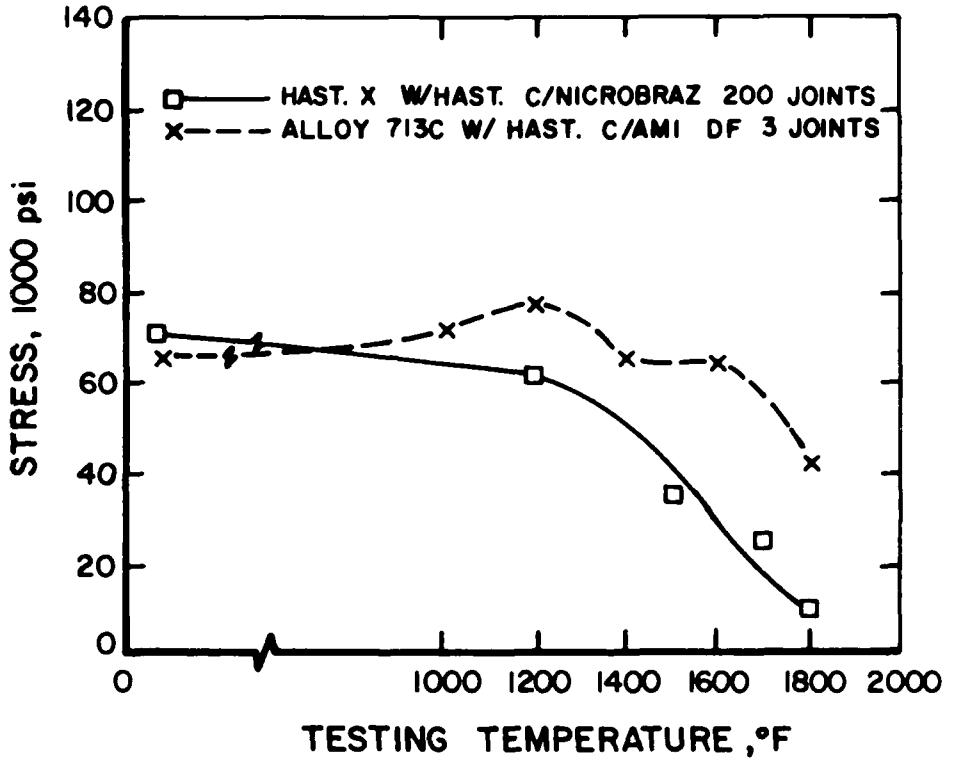


Figure 7. Comparison of tensile strengths resulting from different braze filler metals for varying temperature.

the properties of the superior joint alone. All following tests, then, were conducted on René 80/D 15 joints.

Since variations of tensile strengths with temperature had been determined, a reasonable view of the UTS - temperature - joint clearance surface could be mentally constructed with the knowledge of the UTS versus joint clearance for one high and one low temperature. Accordingly, room temperature and 1800°F (985°C) were chosen as test temperatures. Brazed joints were prepared from R´ 80/D 15 with intended clearances of 10 to 60 mils. After the test bars had been prepared, the joint clearances were measured and the specimens were tensile tested. The results of this effort are listed in Tables 5 and 6 and are graphically displayed in Figure 8.

The data show that there is little or no variation in tensile strength as the joint clearance varies between 10 and 60 mils. This result is true, evidently, regardless of the test temperature. Once again, regardless of joint clearance, the strengths of the René 80/D 15 brazed butt joints compare favorably to that of the base metal.

4.2 STRESS RUPTURE LIVES OF RENÉ 80/D 15 BRAZED BUTT JOINTS IN ALLOY 713C BASE METAL

Superalloys are often put into service under conditions of elevated temperature and sustained load. Consequently the stress rupture life of any superalloy is an important mechanical property of that material. Furthermore, any braze joints in such a material, if they are to be truly

TABLE 5

ROOM TEMPERATURE TENSILE STRENGTHS OF ALLOY 713C TEST BARS WHICH HAD A VARIABLE CLEARANCE BRAZED BUTT JOINT IN THE CENTER OF THE TEST SECTION

Joint Material: -325 Mesh René 80 braze sinter metal with D 15 alloy as a braze filler metal

Joint Clearance (inches x 10^3)	Ultimate Tensile Strength (ksi)
9	110.9
16	109.2
20	117.9
23	126.9
25	119.9
32	126.9
33	125.8
38	122.6
40	126.9
44	129.3
48	127.1
54	122.9

The mean UTS is 122.2 ksi

TABLE 6

1800°F TENSILE STRENGTHS OF ALLOY 713C TEST BARS WHICH HAD A VARIABLE CLEARANCE BRAZED BUTT JOINT IN THE CENTER OF THE TEST SECTION

Joint Material: -325 Mesh René 80 braze sinter metal with D 15 alloy as a braze filler metal

Joint Clearance (inches x 10^3)	Ultimate Tensile Strength (ksi)
5	41.5
9	48.2
14	43.2
19	41.5
30	41.2
34	44.0
36	41.7
38	31.8
43	37.4
44	38.0
56	50.1
58	41.2

The mean UTS is 42.6 ksi.

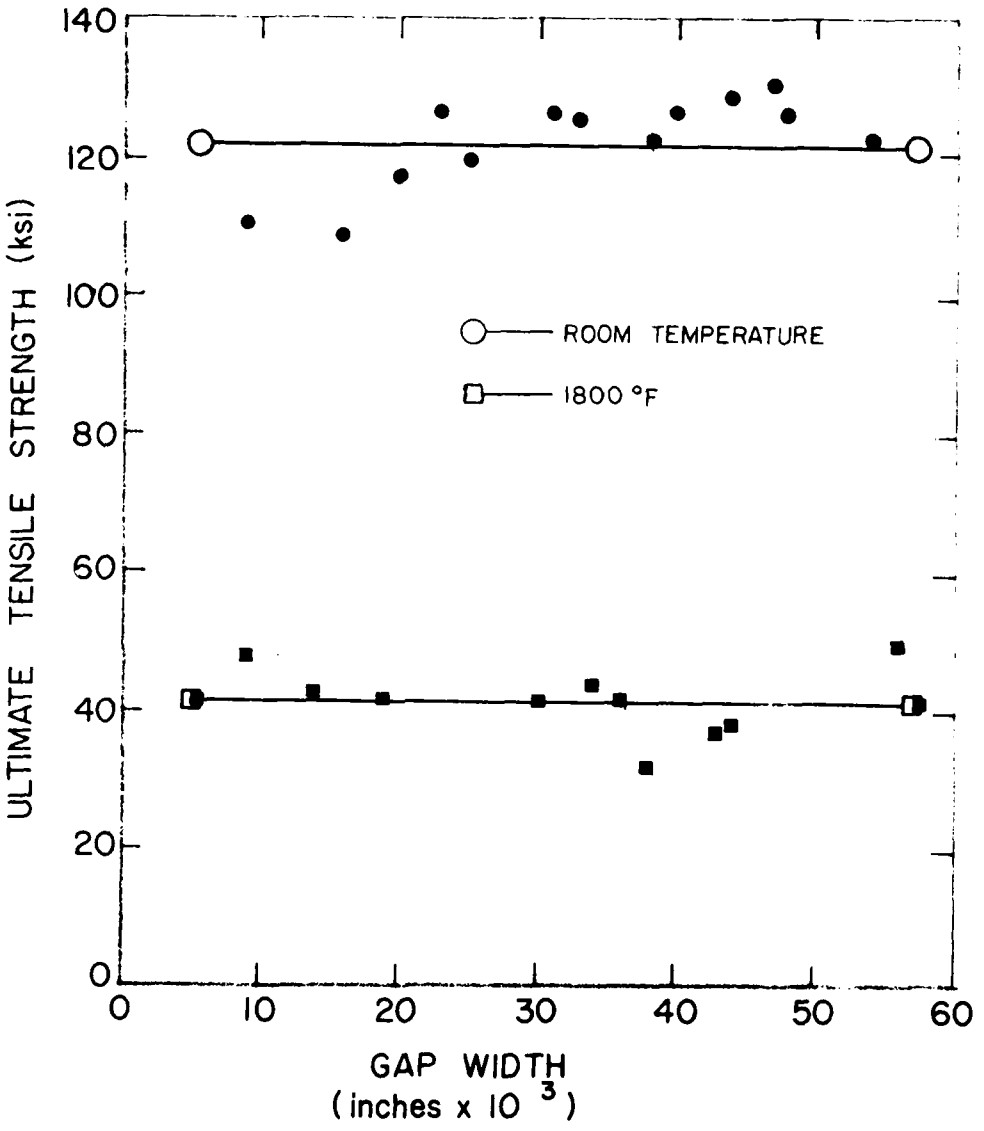


Figure 8. Variations in the ultimate tensile strength of René 80/D 15 brazed butt joints with joint clearance at both room temperature and 1800°F.

functional, should display stress rupture lives that rival the base metal. Because of this the stress rupture behavior of wide clearance René 80/D 15 braze joints in ALLOY 713C was ascertained.

The scope of the investigation did not allow for a comprehensive effort in the stress rupture area. However, since the tensile tests had indicated very little effect of gap size on joint mechanical properties, behavior data taken for a standardized joint clearance was deemed probably sufficient to characterize joints of all widths. Therefore, in keeping with the tensile tests, the joint clearance was standardized at 15 mils for the stress rupture life test.

The test bar used for the stress rupture tests was the same as that used for the tensile tests and a number of them were prepared that had 15 mil clearance butt joints at the center of the gage length. The original intent was to test in duplicate (or triplicate as scatter would dictate) under three to five test conditions. These data would then provide for the construction of a Larsen-Miller type graph and thereby reveal the entire stress rupture behavioral spectrum.

For the initial probe tests, the test conditions were chosen to allow that: if the joint happened to be superior to the base metal, the base metal itself would rupture in some reasonable time. It was also necessary to choose test conditions under which the behavior of the base metal is documented. The stress rupture life of ALLOY 713C, which has experienced 2150°F for 2 hours followed by air cooling, under conditions of 30,000 psi tensile load at 1700°F is reported to be 121 hours.[2] Since the brazing cycle for producing the joint closely assimilates the heat treatment and the rupture time is roughly one work week, the first test conditions were chosen to be 30,000 psi at 1700°F.

The first specimen that was tested failed after 124 hours. This was an astounding result but not totally unbelievable in view of the tensile tests. From this point, a large number of test specimens were expended in an attempt to duplicate the initial result. All fell for short. The data are listed in Table 7 and show the broad and random scatter that is attendant to the stress rupture lives of the brazed butt joints.

Two test specimens were remaining. They were tested under conditions of 55,000 psi stress at 1500°F. These tests were conducted by way of ascertaining whether the rupture life scatter is attendant at all temperatures. These data are included in Table 7 and show that the scatter does remain and that the joint properties are, in general, inferior to that of the base metal.

4.2.1 Discussion of the Stress Rupture Results

The stress rupture data prompt three questions: (1) why is there so much scatter?, (2) why did the life of one joint compare favorably with that expected of the base metal?, and (3) why is such disconcerting behavior not apparent in the tensile test results? Probable answers to the first two questions may be found in Figures 9 through 12. Figures 9 and 10 show a typical tensile test fracture surface and the fracture surface of the 124 hour life stress rupture specimen, respectively. Figure 11 shows a more typical fracture surface of a stress rupture specimen.

The fracture surface of Figure 11 is comparatively smooth and the fracture has occurred inside the joint but near the top* faying surface. This fracture behavior is typical of all stress rupture specimens except

*'top' refers to the faying surface provided by the half specimen that was on top (relative to earth) of the other during braze fabrication of the test specimen blank.

TABLE 7

STRESS RUPTURE LIVES OF 15 MIL CLEARANCE
BRAZED BUTT JOINTS IN ALLOY 713C

Joint Combination:	René 80/D 15
Test Conditions:	30,000 psi at 1700°F in air
Base Metal Life[2]:	121 hours

Rupture Life in hours	Post Braze Heat Treatment
19.1	2150°F, 2 hours, AC
5.0	none
10.0	none
124+	none
20.0	none
6.2	none
15.8	none
49.7	none
21.3	none
9.3	none
17.2	none

Joint Combination:	René 80/D 15
Test Conditions:	55,000 psi at 1500°F in air
Base Metal Life:	292 hours

Rupture Life in hours	Post Braze Heat Treatment
73.5	none
9.8	none

+This bar suffered from two furnace outages. Actual time to failure is untraceable, but it is known to have exceeded 124 hours

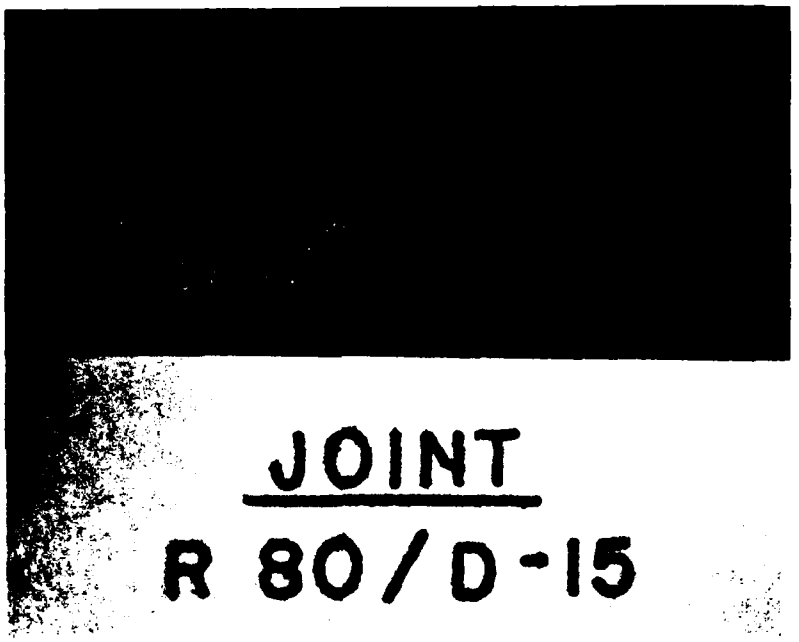


Figure 9. Typical fracture surfaces from tensile failures of a René 80/D 15 brazed butt joint.

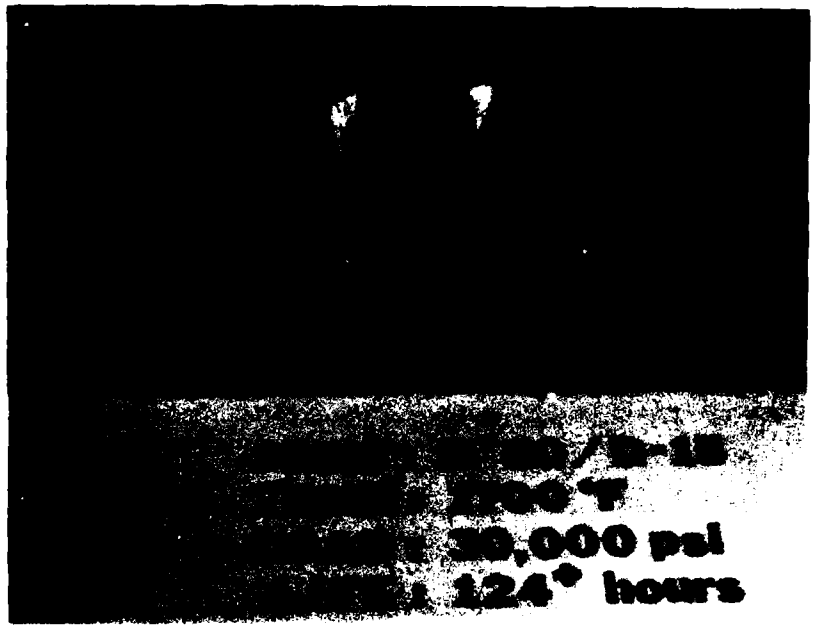


Figure 10. Fractured stress rupture specimen which displayed good life. Photograph shows irregularity of the fracture surface.

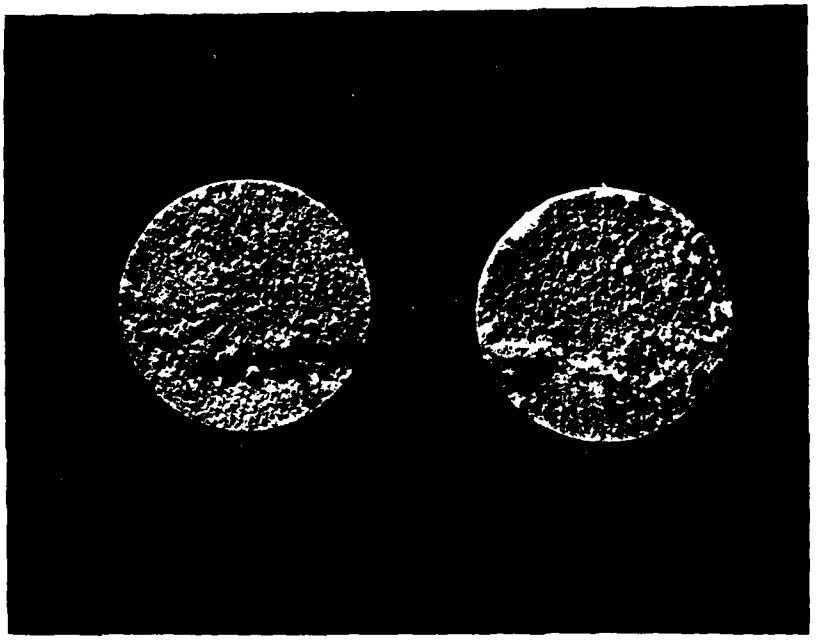


Figure 11. Typical stress rupture fracture surfaces from a René 80/D 15 15-mil joint. Conditions: 1700°F - 30,000 psi.

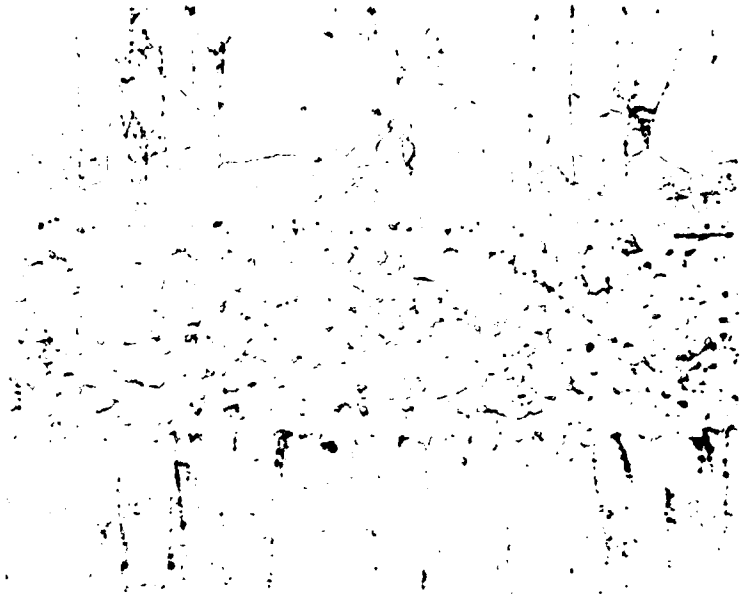


Figure 12a. 15-mil butt joint. 80/D 15/as brazed. (Kalling's etch, 100X.)

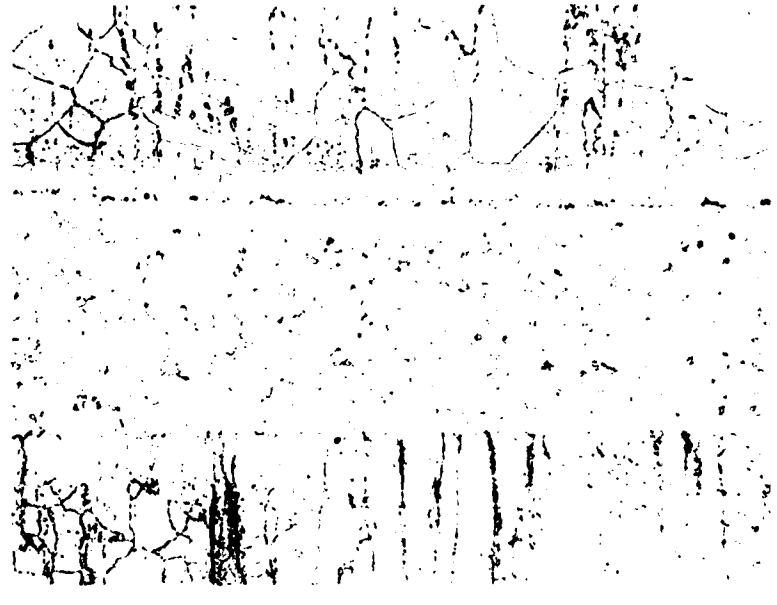


Figure 12b. 15-mil butt joint. 80/D 15/solution and aged. (Kalling's etch, 100X.)

the long lived one. The fracture surface of the long lived specimen (Figure 10) is seen to be the consequence of a non-planar failure that has occurred at mid-joint. This fracture surface is akin to that of a specimen broken by ever increasing tensile loading, i.e., a tensile test specimen as shown in Figure 9.

Figures 12a and 12b are a photomicrograph of a René 80/D 15 joint that was produced during the materials selection phase. Figure 12a shows an as-brazed joint and Figure 12b shows a joint after the following solution and age treatment: 2150°F - 2 hr - AC + 1700°F - 16 hr - AC. Figure 12b shows what is apparently a plane of pores near the upper faying surface; such a plane, if extant, is much suppressed at the lower faying surface. With the observations from Figure 12b as a guide, the same phenomena are readily discerned in Figure 12a, the as-brazed joint. The plane of pores is probably a consequence of the joint making technique. Its presence and degree of extent (severity) from specimen to specimen almost surely gives rise to the observed scatter in the stress rupture results. The long lived specimen then probably did not contain such a plane of pores.

The question of why there was so much scatter in the tensile test results cannot be answered but considerable light was shown upon that parameter by the thermal fatigue tests.

4.3 THERMAL FATIGUE LIVES OF RENÉ 80/D 15 ALLOY BRAZE BUTT JOINTS IN ALLOY TBC BAR MATERIAL

The metallurgical engineering community generally accepts that many hot stage gas turbine engine component's suffer thermal fatigue failures that result from the service conditions. Thermal fatigue failures surely occur at positions within the component where such actions as start-up and shut-down of the engines as well as power surges and repressions cause alternating periods of tensile and compressive stresses because of the attendant alternating

periods of high and low temperatures. When a component is prone to such a failure mode, a crack may initiate during some period of tensile stress and then lengthen and broaden as it suffers continuing periods of tensile stress caused by engine operation. Such a crack often falls into the wide clearance category, and the braze repair of such an area is required to tolerate the same service conditions that provoked the initial crack. It was thus necessary to ascertain the thermal fatigue resistance of the wide clearance brazed butt joints.

4.3.1 Thermal Fatigue Testing Conditions and Apparatus

The most common method of thermal fatigue testing is well known to metallurgical engineers. In this test, the middle of the sharp edge of a wedge shaped specimen is subjected to alternating periods of flame heating followed by rapid air cooling. The thermal fatigue life of such a specimen is then the number of cycles that it sustains before it develops a crack. The technique is sometimes modified by close control of the flame and air impingement zone as well as control over the uniformity of heating and cooling throughout that zone. Further sophistication may be employed through control of the flame and air temperatures during each cycle.

In spite of these sophistications the common technique for assessing thermal fatigue life was suspected of being unable to generate results that would be germane to the mechanical properties requirements of a braze repaired engine component. Moreover, it was quite difficult to construct a reasonably noncontroversial test specimen for the common technique which would both simulate service requirements and at the same time be representative of wide clearance brazed butt joints. Therefore, a different technique was used to assess the thermal fatigue lives of brazed butt joints for the application to engine component repair.

Nippes[3] has reported the use of a thermal fatigue testing technique that involves the use of a Duffers "Gleeble". Although this machine was developed to simulate heat affected zones in welds, it is readily fitted with a fixture for conducting a new kind of thermal fatigue test. For the test, a specially designed test specimen is rigidly clamped in a rigid, water cooled fixture that fits onto the "Gleeble" machine. Heating is accomplished by passing a controlled electrical current through the specimen. Cooling is accomplished by radiation to and convection by the atmosphere as well as conduction to the water cooled reservoirs of the clamping fixture. During the heating portion of the cycle, due to the would be thermal expansion of the specimen's test section being constrained by the rigidity of the clamping fixture, the specimen experiences thermally induced compressive stresses. During the cooling and due to eventual compressive deformation, the specimen experiences tensile stresses. Eventually, a crack will form or the specimen will break to conclude the test.

Figure 13 is a photograph of this setup as used for thermal fatigue testing. The electronic component in the foreground is an electronic pyrometer used to measure mid test span temperatures and is part of the feedback loop used for controlled heating and cycling. The Duffers "Gleeble" used for thermal fatigue testing of wide clearance brazed butt joints in ALLOY 713C was a Model 510. The control panel for this machine is pictured in Figure 14. In the middle of the left most control panel may be seen a set of helipots. It is possible to set each of these 'pots' to tap a percentage of some prescribed milivoltage and feed it to the machine; it is also possible to set the time over which these milivoltages are output by linear increase from lowest to highest over the time interval. These milivoltages are cumulative from pot to pot and the machine then causes, by passing current through the specimen, the pyrometer output to match (and follow) that from

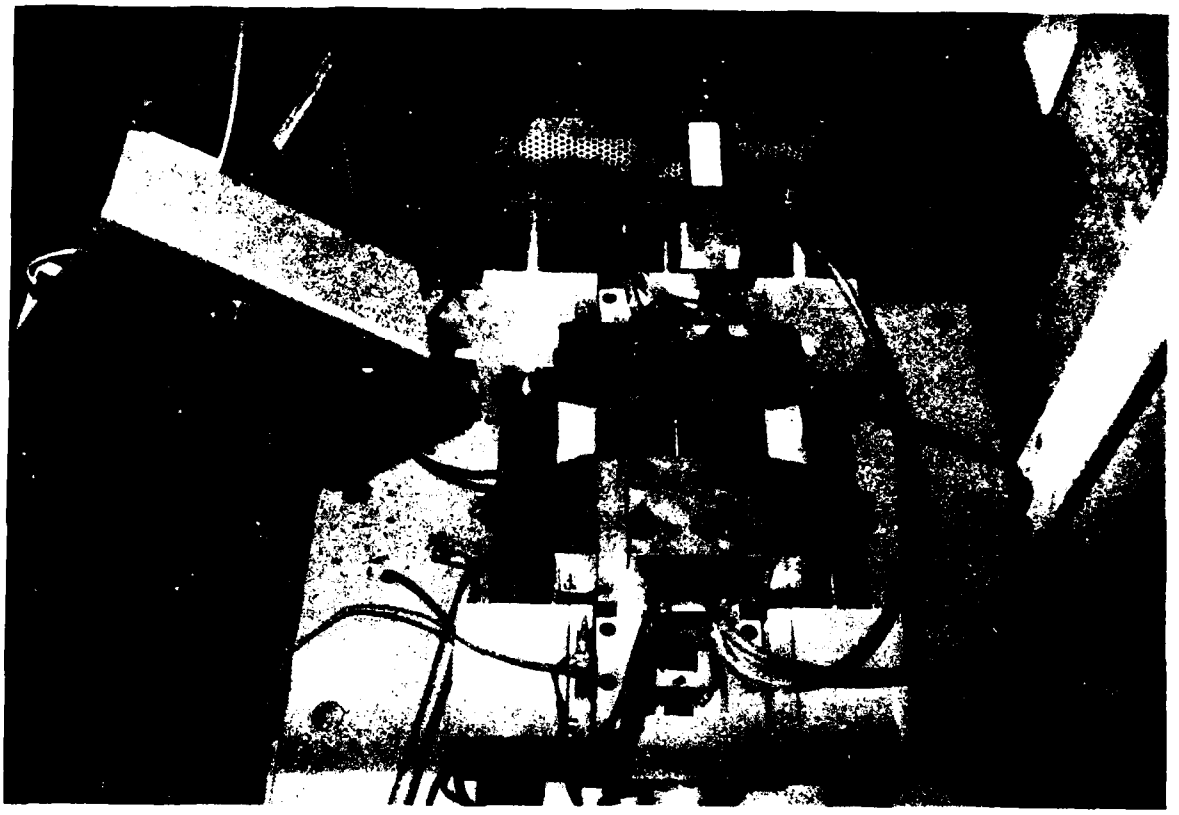


Figure 13. The Duffers "Gleeble" thermal fatigue testing apparatus. Specimen is seen in the test fixture.

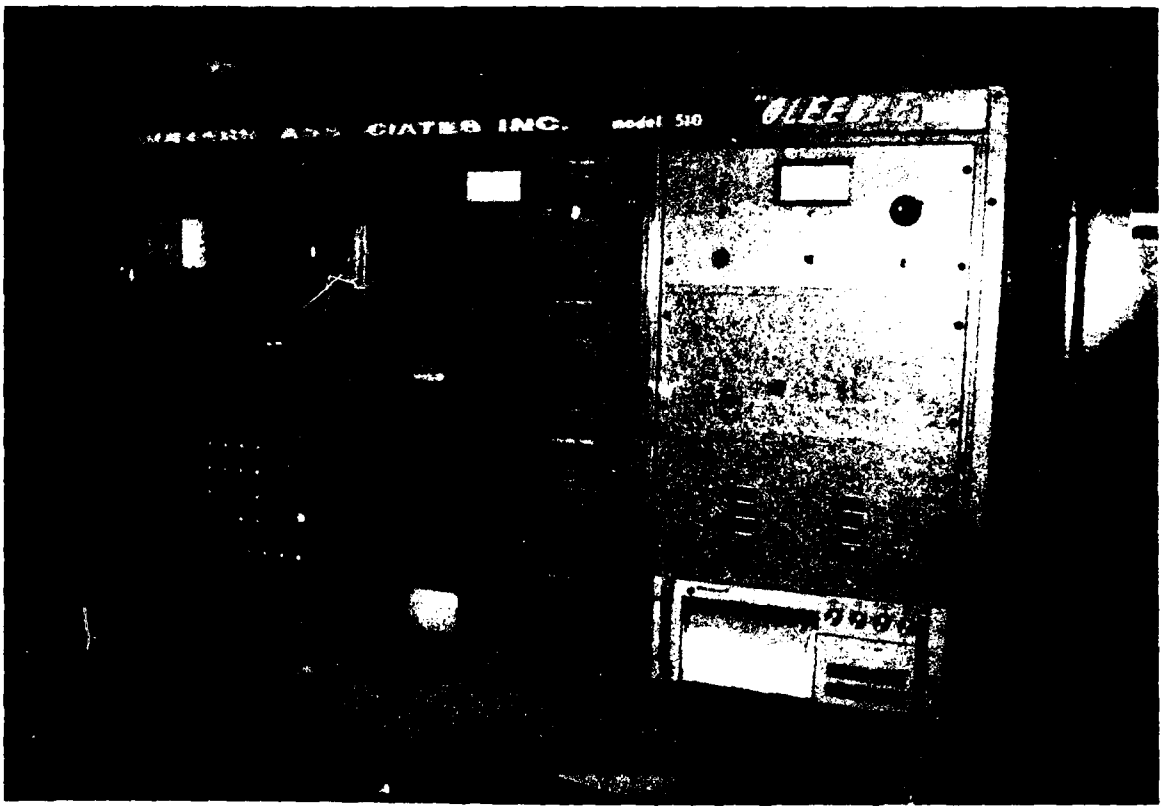


Figure 14. Control panels of the Duffers "Gleeble" Model 510.

the helipot panel. In this way, the heating cycle of the midspan of the test specimen can be precisely controlled. It is possible also to set the total time of a cycle and the machine can be caused to repeat the sequence automatically until it is physically interrupted either manually or by an open circuit caused by specimen failure.

The heating cycle that was used for the thermal fatigue tests was somewhat arbitrary but did take into account the probable exponential nature of heating and cooling during the start-up and shut-down of a gas turbine engine. Such heating is thought to be exponential but cannot be truly exponential because the engine must eventually reach a steady operational state where the heating rates are zero. Consequently, the heating period was assimilated by a parabolic curve form where heating began at ambient temperature and reached a pre-set peak temperature at the same time that the heating rate became zero. To simulate steady operation, the temperature was held at the peak temperature for a prescribed length of time and then the specimen was allowed to cool.

The cycle that was used for all thermal fatigue testing was: (1) parabolically heated from room temperature to 1832°F (1000°C) over a time span of 30 seconds, (2) hold at 1832°F for 5 seconds, and finally (3) allow to cool for 85 seconds. The cycle time was thus 2 minutes. This cycle was repeated until some form of failure occurred. Cycles to failure were then calculated by dividing the total clock time by the cycle time.

4.3.2 Testing Procedure and Results

A picture of the thermal fatigue test bar may be seen in Figure 15; it is a duplicate of the specimen used by Nippes[3] in the aforementioned early studies. Blanks for this specimen were prepared by butt braze assembly, and the joint clearances ranged from 17 to 76 mils (for details of these

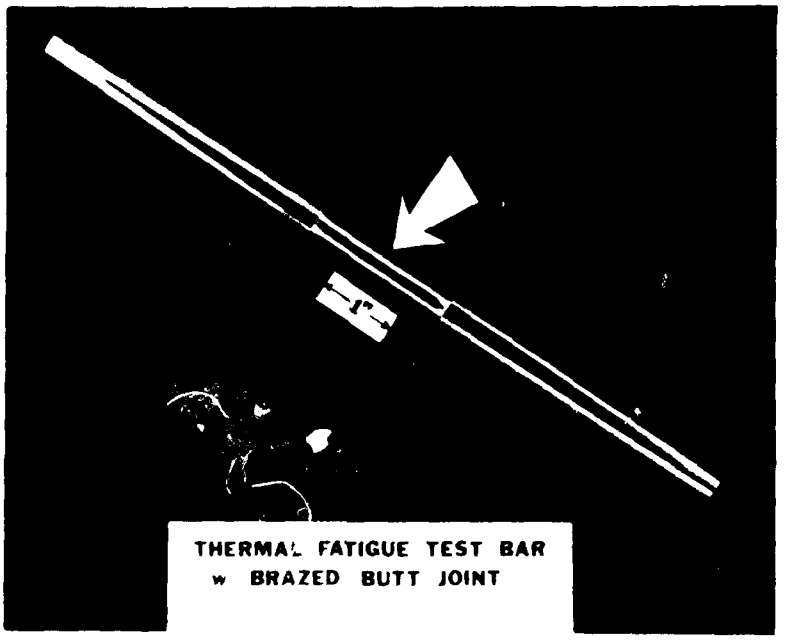


Figure 15. Typical thermal fatigue test bar.

fabrications see Addendum 3). Also prepared were three test specimens that were made by welding mild steel tabs to both ends of a 5-inch section of as-cast ALLOY 713C. These specimens when machined provided three test specimens whose test spans were ALLOY 713C. Testing of these specimens provided data on the thermal fatigue life of the base metal and provided a base line for comparison of the thermal fatigue performance of the braze butt joined specimens. The data resulting from these tests are seen in Table 8.

4.3.3 Discussion of the Thermal Fatigue Tests

The form of the thermal fatigue test employed for the brazed butt joints has the effect of imposing the thermally induced stresses across and perpendicular to the faying surface planes of the joint. This is surely the manner in which such stresses would be imposed by service conditions on a thermal fatigue crack area that had been repaired by wide clearance brazing techniques. For these reasons plus the fact that heating rates have been carefully controlled to simulate service conditions, the results of these thermal fatigue tests are clearly more directly applicable to probable service performance than would be those of the more commonly accepted thermal fatigue testing procedure.

The facts that the data are widely scattered and that no test returned results that would favorably compare with this property for the base metal combine to form similarity between the property and stress rupture life. Since, moreover, all joint failures were actual breaks while those of the parent metal specimens were cracks and joint failures were all faying surface failures, the reason for this less than attractive behavior is probably the same as for that of stress rupture, i.e., a plane of pores at or near the upper faying surface.

The data, as they stand, offer no explanation regarding why no single joint had fatigue resistance that rivaled that of the base metal.

TABLE 8

THERMAL FATIGUE LIFE* OF VARIABLE CLEARANCE
BRAZED BUTT JOINTS IN ALLOY 713C

Joint Combination: René 80/D 15 Alloy

Base Metal Life: 1366, 2093, 2255 Cycles

Joint Clearance (inches x 10^3)	Cycles to Failure	Joint Clearance (inches x 10^3)	Cycles to Failure
17	87	43	1
18	39	55	18
18	225	58	13
24	67	60	36
32	599	64	41
34	86	76	10

*Cycle is parabolic heating from R.T. to 1832°F in 30 sec, hold at 1832°F for 5 sec, cool in test rig for 85 sec. Repeat.

Whether good mechanical properties overall could be achieved by improving the joint making technique to eliminate the plane of pores is a matter of conjecture or further investigation, should circumstance justify it. Regardless, when the joint making techniques used here are employed to repair thermally induced fatigue damage, great care should be exercised in producing the joint to ensure against porosity and strong considerations should be afforded to the eventual service conditions.

SECTION 5
DISCUSSION

The two objectives of this work were to develop techniques for making sound wide clearance butt brazed joints in a γ' type alloy and to determine, at least cursorily, the mechanical properties of such joints. The mechanical properties of butt brazed joints are not commonly of interest. More commonly, the mechanical properties of brazed lap joints are tested because (1) brazed joints are felt to be much better performers under shear load than under tensile load, (2) it is usually possible to engineer a brazed assembly design so that the brazed joints will experience mostly shear stresses while in service, and (3) besides, sound butt joints of any appreciable area are difficult to make. The intended application of the results of this work lay in the braze repair of service damaged gas turbine engine components that are from the hot stages. One type of service damage is cracks; metals do not typically crack in compression or shear but they do crack under sufficiently high or repeated cycles of tensile stress. Cracks that form in service occur at points on the component where there is tensile loading; if such a crack is repaired by brazing thus producing a brazed joint, that joint must sustain tensile loading while in service. It was therefore necessary to ascertain the mechanical tensile properties of wide clearance joints and this requirement dictated that such joints be butt type.

The fact that hot stage engine components were the principal interest and that such components are nearly always made of γ'-type alloys caused the requirement that the brazed butt joints be made in a γ'-type alloy. The braze repair of such components and the production of such joints are usually

difficult. Both, however, are readily accomplished when the repair procedure is preceeded by fluorocarbon cleaning of the γ' type components involved.

The base metal alloys that were chosen for screening during this effort were picked from generic groups because they were (are are) considered to be representative of their groups. No further defense of the choices of specific alloys can be made. The choice of ALLOY 713C as the base metal to be used in the mechanical testing phase may, however, have been fortuitous. In other work on component braze repair it has been found that at least one γ'-type alloy, C-1023, cannot sustain the FCP and brazing cycles without its metallurgical properties being unrestorably compromised. It has been fortunate that ALLOY 713C does not have this malady because such possible circumstances were not taken into account when choosing the base metal.

The brazing powders, both the braze sinter metals and the braze filler metals, were chosen for their representation of generic groups. Many other brazing powders could have been chosen without detriment to the program. The fact that any brazing alloy was not included in the joint making materials screening should in no manner be considered an indictment of that alloy. Moreover, brazing alloys that were not chosen as joint making materials should not be disparaged on the basis of this investigation. It was necessary to choose alloys based on cursory investigations under rigid and narrow brazing procedural limits. The final choice of brazing powders then can have no more significance than is implied with regard to the foregoing constraints.

The brazing powder screening effort did show that not all brazing filler metals will readily every brazing sinter metal under arbitrary brazing conditions. Therefore, when

wide clearance brazed joints are made, at least by the two step method, the joint making combination should be suspect until proven sound.

With regard to the wide clearance brazing technique (which, incidently, is also applicable when materials build-up is required) there are evidently two procedures, namely, the one and the two step method. The two step method was the one used for this investigation. It is also a matter of the art to use a one step method. In this method, the braze sinter metal is mixed with the braze filler metal and that mixture is placed in and on the crack to be repaired. The repair then takes place in a single brazing step. Evidently, the drawback to this method is the requirement that the braze filler metal be 50 percent or greater of the mixture. In the two step method this is reduced to 35%, and thus when a sound joint is produced it should be metallurgically superior to that produced by the one step method. In the joint making of this effort braze filler metal feeder rings were used in an effort to secure complete fills and sound joints.

The effort to secure sound butt joints was somewhat successful. However, at least for the joint combination René 80/D 15 alloy, a plane of pores apparently often forms at or near the upper faying surface during the production of a butt brazed joint. These pores appear to have been entrapped by the brazing filler metal as it rose from the lower to the upper faying surface. There is little reason to believe that such entrappments would occur during the repair of an engine component but this should be established. The plane of pores was unfortunately overlooked during the materials selection efforts. This situation is accounted for by reference to the fact that, at the time, the only scuttling criterion was lack of fill. When superb filling was seen to exist, the plane of pores was simply but unfortuantely not noted. Its significance surfaces as the mechanical properties spectrum unfolded.

The mechanical properties of wide clearance brazed butt joints have not truly been thoroughly divulged by this work because, on final assessment, it was found that most of the joints evaluated here had the plane of pores defect. To that extent what are now known are some mechanical properties of such joints. If such joints could be made without the plane of pores, the results of the stress rupture tests and the thermal fatigue test would likely be quite different. In particular, the scatter would almost certainly be ameliorated. Whether these properties of sound joints would compare favorably with the base metal cannot be ascertained at this juncture. Neither can the effects of joint clearance or temperature be conjectured.

The tensile properties of the butt joints tell a different story. Because the tensile fractures were rough surfaced and occurred at mid-joint-span, they were obviously not controlled by any plane of pores. The tensile tests were therefore true tests of the butt joint and as such are revealing. It is shown by the results of the René 80/D 15 joints that wide clearance brazed butt joints can be made that have tensile strengths as good as, and sometimes superior to that of the base metal. They also show that the foregoing is true throughout broad temperature ranges. The tensile test results from the Hastelloy C/AMI DF 3 joints show that not all joints are equal, that some joint making combinations result in higher performances than others, and indicate that the best joints contain some γ' forming constituents.

The tensile tests show further that joint clearance has little if any influence on tensile performance. This is true for any joint making materials and is encouraging because it demonstrates that a good joint can be depended upon to perform well regardless of its width which is not true when the brazing is done with filler metal alone.

The only basic difference between the mechanical properties tests performed is strain rate. It can only be concluded that in the case of the tensile tests either, for some reason, the specimens did not contain a plane-of-pores defect or such defects only become the controlling factor when strain rates are low. It does seem probable, however, that if René 80/D 15 joints that do not contain the plane-of-pores defect can be made, the results of testing their mechanical properties would be uniformly encouraging. It also seems probable that the same could be said for any number of joint making combinations so long as such joints contained a γ' forming constituent.

SECTION 6
CONCLUSIONS

1. Any γ'-type superalloy, regardless of surface condition, can likely be rendered nickel brazeable by fluorocarbon cleaning.

2. It is surely possible to repair wide clearance cracks in service damaged, hot stage components from gas turgine engines by nickel brazing when the component is first fluorocarbon cleaned followed by filling the crack with a braze sinter metal and sintering it in plane and finally completing the repair by placing a compatible braze filler metal on the repair area and brazing by a proper cycle.

3. Provided that an adequate braze sinter metal - braze filler metal combination is chosen and the resulting repair is likely to perform as well or better than the base metal in service.

4. The mechanical properties of wide clearance butt brazed joints can vary broadly with different choices of braze sinter metal - braze filler metal combinations.

5. Although all braze filler metals are compatible with all γ'-type alloys, once the alloys have been fluorocarbon cleaned, not all braze filler metals will wet all braze sinter metals, i.e., joint combinations are special.

6. When wide clearance brazed joints are made, their mechanical properties are, in general, not reproducible (reliable) unless the joints are free of serious defects. Moreover, securing this condition evidently requires careful and, at this juncture, unknown procedures.

SECTION 7

LIST OF REFERENCES

1. "Brazing of Hastelloy X with Wide Clearance Butt Joints," Technical Report AFML-TR-79-4026, March 1979.

2. "Engineering Properties of Alloy 713C," International Nickel Co., Inc., November 1968, p. 6.

3. E. F. Nippes and J. C. Uy, "A Method of Investigating Low Cycle Thermal Fatigue," Welding Journal, 46, 8, August 1967.

ADDENDUM 1

INTERIM TECHNICAL REPORT NO. 1

DEVELOPMENT AND EVALUATION OF WIDE GAP BRAZE JOINTS IN GAMMA PRIME ALLOYS

CONTRACT F33615-79-C-5033

INTERIM TECHNICAL REPORT

No. 1

30 April 1980

J. W. Chasteen

University of Dayton
Research Institute
Dayton, Ohio 45469

FOREWARD

This Interim Technical Report covers the work performed under Contract No. F33615-79-C-5033 during the period May 1, 1979 to February 1, 1980. It is published for information and the conclusions herein are those of the contractor alone.

This contract, with the Welding and Joining Group of the University of Dayton Research Institute, was initiated under the title "Development and Evaluation of Wide Gap Braze Joints in Gamma Prime Alloys." The work is being administered under the technical direction of Dr. G. E. Metzer of the Air Force Materials Laboratory, Metals and Ceramics Division, Wright-Patterson Air Force Base, Ohio.

The program is being directed by Dr. A. F. Ray, Project Supervisor, Metals and Ceramics Division. The principal investigator is Dr. J. W. Chasteen of the Welding and Joining Group.

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*Combinations codes read: braze sinter metal-cement-braze filler metal where 108 = Nicrogap 108, C = Hastelloy C, R80 = René 80, S = Nicrobraz 'S' binder, 500 = Nicrobraz Cement No. 500, 200 = Nicrobraz 200, 4777 = AMI 4777 (BNi-2), and DF-3 = AMI DF-3.

LIST OF ILLUSTRATIONS (CONTINUED)

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SECTION 1
INTRODUCTION

The first few turbine stages of advanced gas turbine engines must operate at temperatures which exceed the safe operating levels for stainless steels and solid solution superalloys. Engine components for these stages are often made from γ' hardened nickel base superalloys. Such components have become rather intricate in the air cooling techniques used and in their assembly (mechanical and brazed). Until recently, braze assembly of such components was marginal, and the technology for braze repair of such parts, upon retirement from service, was limited. The fluorocarbon cleaning process recently developed at UDRI now makes possible routine assembly and repair of γ' alloy engine components by standard nickel brazing techniques.

The physical properties of brazed joints and particularly wide clearance brazed joints have long been questionable. Consequently, welding is conventionally employed for assembly and repair of gas turbine engine components. Welding, however, has limitations in that it is a piece-by-piece, as opposed to a batch, operation and also it may not be possible to physically access the joint with a welding torch. In addition to these limitations, it is generally not possible to weld (or even braze) gamma prime type alloys by heretofore known art. As aforementioned, it has become possible to nickel braze gamma prime type alloys, even after service, if they are prepared by fluorocarbon cleaning prior to brazing. Since brazing is now available for such metallurgical systems and welding is still not an option, it is advisable to determine the physical properties of wide clearance nickel brazed joints in gamma prime alloys.

Such determinations are currently being conducted at UDRI under the auspices of USAF Contract No. F33615-79-C-5033, titled

"Development and Evaluation of Wide-Gap Braze Joints in γ' Alloys." What follows is an interim report on the first phase of the subject effort.

SECTION 2
PHASE I: BRAZE-JOINT COMPOSITE

2.1 OVERVIEW OF PHASE I

It is not within the scope of the present program to definitively delineate between potential brazing materials. Nor is it within the present scope to characterize the properties of such joints in a large number of gamma prime alloys. It was however necessary to cursorily investigate joint making materials in order to judiciously choose materials for the physical properties evaluations. Although the experience of UDRI personnel made Alloy 713C the best candidate as the parent γ' alloy, it was possible to include two other γ' alloys in the screening investigation. In order that the results of this investigation might enjoy a maximum impact, the γ' alloys and the brazing materials of this effort were limited to only those that are commercially available.

For what follows, it is necessary to define "wide-clearance" joint. A wide clearance gap is understood to be any potentially brazable gap that is so wide that a braze filler metal, by reason of its fluidity or surface tension, but not wettability, will not bridge and remain in the gap. Such a gap, if filled by any brazing technique, is here termed a "wide-clearance joint." A braze joint of the type described is typically constituted of two specific materials: (1) a braze sinter metal and (2) a braze filler metal. The braze sinter metal is, for the purposes here, a powder whose bulk composition corresponds to a melting point that is significantly higher than that of the braze filler metal with which it is to be mated. The braze sinter metal is placed in the wide clearance gap and lightly sintered in place--thereby presenting a porous bridge which can be filled by a later application of the braze filler metal. This latter application completes the joint.

The two materials that make up a wide clearance joint must each have two minimal characteristics. The braze sinter metal

must be lightly sinterable at reasonable temperatures (below the heat treating temperature of the parent alloy) and it must be fillable (wettable) by the braze filler metal. The braze filler metal must melt and flow at a reasonably low temperature and wet the parent alloy. It must also, of course, wet and fill a sintered compact of the braze sinter metal.

2.2 TASK 1. COMPATIBILITY OF THE BRAZE FILLER METAL AND THE PARENT ALLOYS

2.2.1 The Parent Alloys

Three specific γ' alloys have been screened as potential parent alloys. The properties evaluation program will center on Alloy 713C which is considered to be a medium alloyed gamma prime. The screening included also a modestly alloyed gamma prime in the form of Inconel X-750 and a strongly alloyed gamma prime in the form of Mar M 246. Wide clearance brazed joints are likely to be advantageous on γ' surfaces of three types. They are: newly cast and buffed, surfaces having atmospheric corrosion product, and surfaces that emerge upon stripping of a chrome-aluminide type protective coating. The wettability of such surfaces has been investigated; tests of the stripped surfaces are incomplete at this time and will be reported later.

2.2.2 The Braze Filler Metals

The braze filler metals also divide into three generic groups which are characterized by their brazing temperatures. The groups (all nickel base) are (1) low melting--brazing temperature ~1900°F, (2) medium melting--brazing temperature ~2100°F, and (3) high melting--brazing temperature ~2200°F. The brazing alloys that were chosen to represent these groups were BNi-2, Nicrobraze 200, and AMI DF-3 respectively. Metallurgical considerations would indicate that a brazed joint would be stronger if it contained some gamma prime formers such as Al or Ti. In view of this, a fourth braze filler metal was included in the screening investigation. It is a new, proprietary brazing alloy which contains a modest amount of Al and is known as D-15 (see Table 1).

2.2.3 The Compatibility Studies

The braze filler metal-parent alloy compatibility studies were conducted by use of T-bars. T-bars were made from pieces of the parent alloys by placing the edge of one piece upon the flat of another to form a T-joint of near zero clearance (never exceeding 0.001-inches). The assembly was completed by weld tacking the ends of the T-bar with a TIG torch. Sufficient T-bars of each parent alloy were prepared so that each surface condition could be evaluated for each parent alloy and each braze filler metal.

The compatibility was assessed by first placing a small pile of braze filler metal on one side and at one end of each T-bar. This assembly was then placed in a vacuum furnace and heated to the recommended brazing temperature where it was held for 1/2-hour. After this brazing cycle, the compatibility was assessed as follows: if the braze filler metal melted and formed a ball but did not run along the joint the compatibility is nil. Perfect compatibility was construed to be that circumstance where the filler metal melted, ran the full length of the T-bar joint, ran under the near zero clearance junction, and made a braze fillet on the opposite side from where the braze was placed.

2.2.3.1 Sources of the Parent Alloy T-bar Materials

The T-bars were assembled from readily available materials. The Mar M 246 T-bars were assembled by use of slicings from a casting gate that was courteously furnished to UDRI by Detroit Diesel Allison Division, GMC, Indianapolis, IN. The Inconel X-750 T-bars were made from sheared and dressed pieces of 1/8-inch thick sheets of that material which were on hand. The Alloy 713C T-bars were fabricated from sections of extrusions as furnished to UDRI by the Joining and Processing Group at AFML. These latter were heat treated to simulate cast conditions by first solution treating at 2150°F for 2 hours followed by a stabilizing treatment of 16 hours at 1700°F[1].

2.2.3.2 The Parent-Braze Compatibility Tests

2.2.3.2.1 Freshly Cut and Buffed Surfaces

Figures 1a-1c show the results of T-bar run tests where the surfaces are freshly cut and belt ground. The materials and brazing cycles are indicated. Figure 1a shows the placement of the braze, Figure 1b shows the braze side of the T-bars after brazing, and Figure 1c shows the fillet sides of the T-bars. All alloys demonstrate complete compatibility with all braze filler metals when the surfaces are in the fresh cut and buffed condition.

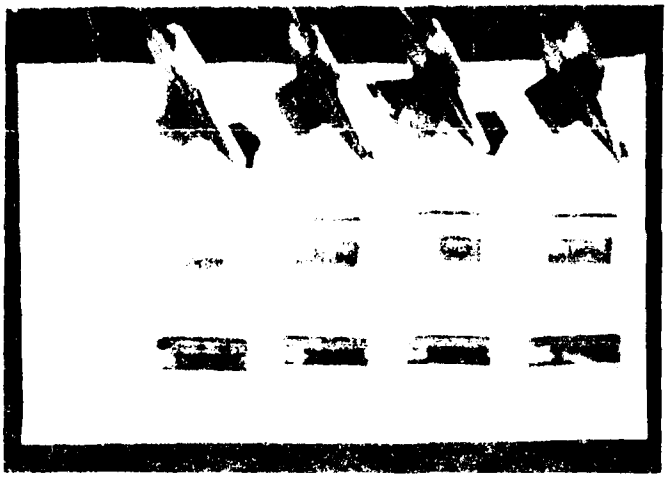
2.2.3.2.2 Pre-oxidized and Grit Blasted Surfaces

In order to simulate "returned from service conditions" for uncoated parts, two full sets of T-bars were oxidized in air furnace for 16 hours at 1700°F. These conditions, in all cases, resulted in a moderately heavy but adherent film. Insofar as was possible, the film was removed by grit blasting. The fact that the T-bar junctions could not be reached by the blasting operation was construed to be a good simulation of a crack that had formed in service.

One set of the resulting T-bars were then brazed by the aforementioned cycles. The results are shown in Figures 2a and 2b. Figure 2a clearly shows that all braze runs were incomplete on the Alloy 713C T-bars; BNi-2 and DF-3 are incomplete on the Inconel X-750 T-bars; but all runs are complete on the Mar M 246 T-bars. Figure 2b shows that none of the fillet sides of the T-bars are wetted except for DF-3 braze filler metal on the oxidized Mar M 246 T-bar. Although it is not apparent, however, even in this case, the weld tacks were not wetted.

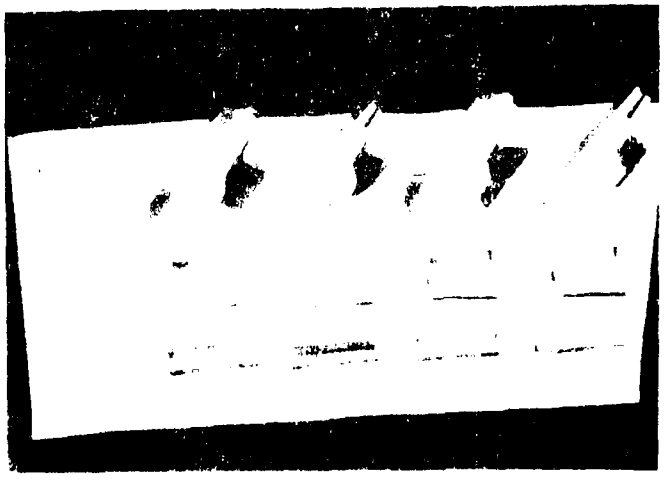
2.2.3.2.3 Pre-oxidized, Grit Blasted, and Fluorocarbon Cleaned

The second full set of γ' alloy T-bars were fluorocarbon cleaned prior to brazing. The results



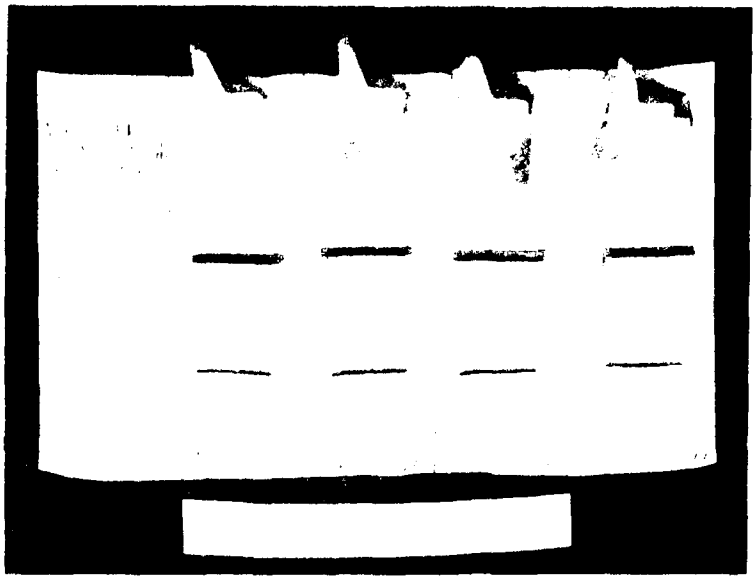
(a) prepared for brazing

(b) brazed: braze side



(c) brazed: fillet side

M 246, Inconel X-750, and
, BNi-2, B-15, and AMI DF-3
surfaces are in the fresh



(a) brazed: braze side

(b) brazed: fillet side

[illegible] 46, Inconel X-750, and [illegible] with [illegible], D-1-2, D-15, and AMI DF-3 [illegible] where the metal surfaces have been pre- [illegible] and brazed.

of the brazings are shown in Figures 3a, 3b, and 3c. Figure 3a shows the placement of the braze. Figures 3b and 3c show the braze side and the fillet side respectively. Obviously, after fluorocarbon cleaning, all pre-oxidized alloys have demonstrated complete runs; complete fillets have been made on all sides opposite the braze. Perfect compatibility between all γ' alloys and all braze filler metals results after the alloys have been subjected to fluorocarbon cleaning.

2.2.3.2.4 Discussion: Parent-Braze Compatibility

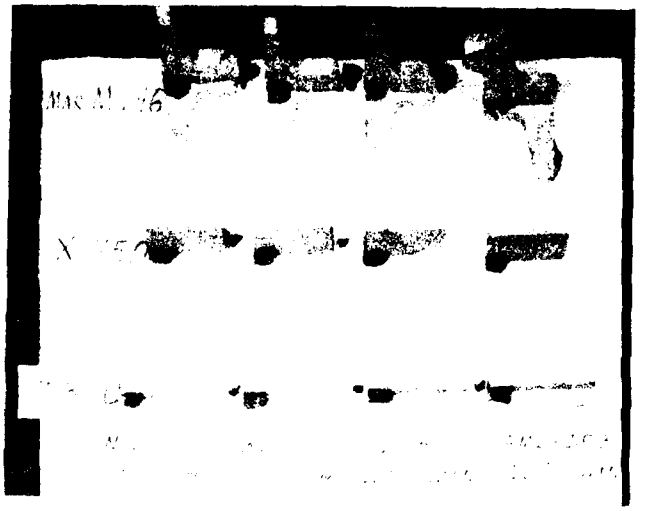
The metallurgical integrity and disposition of the brazed joints in T-bars have not been investigated but several points of note have emerged from the standpoint of braze compatibility alone. They are:

1. When the surfaces of the parent γ' alloys are freshly cut and buffed, they are readily brazable by nickel brazing in standard cycles.

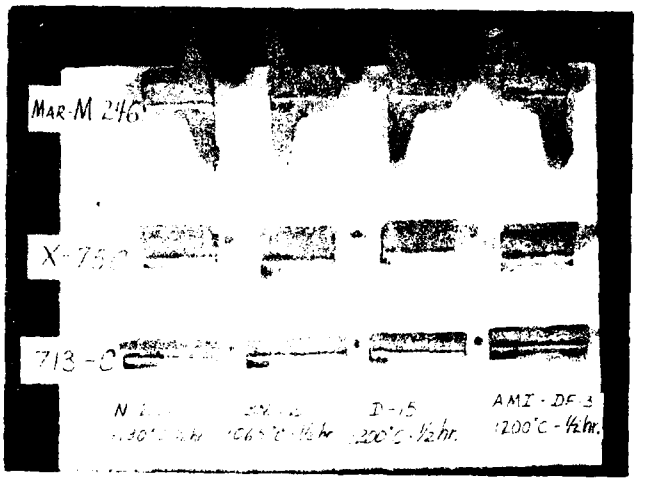
2. When the surfaces have been exposed to a high temperature, oxidizing atmosphere and then only grit blasted, Mar M 246 becomes marginally brazable by braze filler metal DF-3. Mar M 246 with the other braze filler metals and Alloy 713C and Inconel X-750 with all braze filler metals are unacceptably brazable.

3. All of the γ' alloys become readily nickel brazable by all braze filler metals when such alloys are fluorocarbon cleaned prior to brazing.

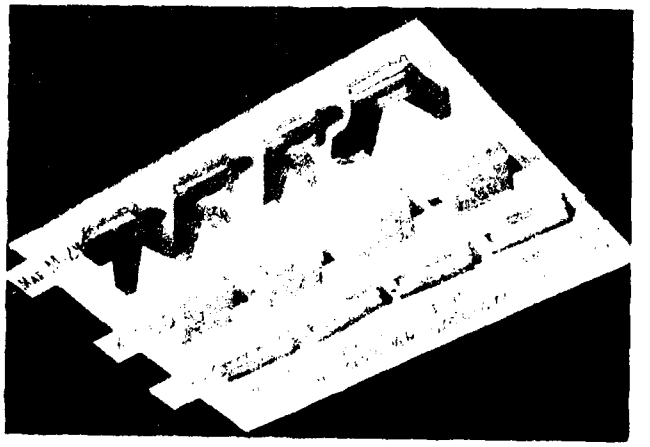
4. Since the thrust of this work involves nickel braze joints in γ' alloys after fluorocarbon cleaning, the T-bar compatibility tests have failed to eliminate any candidate braze filler metal or even delineate between them.



(a) prepared for brazing



(b) brazed: braze side



(c) brazed: fillet side

[illegible] Inconel X-750, and [illegible], BNi-2, D-15, and AMI DF-3 [illegible] surfaces have been pre- [illegible], and fluorocarbon cleaned.

2.3 TASK 2. COMPATIBILITY OF THE BRAZE FILLER METALS WITH THE BRAZE SINTER METALS

The primary requirements of a braze sinter powder are (1) that it partially sinter at a reasonable temperature and thus present a porous infrastructure to be filled by the braze filler metal and (2) that the partially sintered structure have contiguous porosity and be wetted and filled by at least one braze filler metal.

2.3.1 The Braze Sinter Metals and Their Wafers

The braze sinter metals chosen for evaluation were Nicrobraz 150 (mesh size: -140), Hastelloy Alloy C (mesh size: -140, +325), and René 80 (mesh size: -325). As a matter of documentation, Figures 4a-4c are 1000X electron photomicrographs of the raw powders of the braze Sinter Metals. It may be noted that although the René 80 particles and the Hastelloy C powders are spherical, the Nicrobraz 150 is not. Also as indicated by the mesh sizes, the René 80 particles are smaller than those of the Hastelloy C. No particular significance is attached to these observations but perhaps the René 80 particle size is too small. The chemical compositions of all metal powders for this study are listed in Table 1.

The technique of evaluating sinter-filler metal compatibility by brazing a pre-sintered wafer has been previously reported[2,3], and that technique has been used here. For purposes of clarity the technique will be cursorily described. A wafer is made by mixing 2 cc of braze sinter metal with an appropriate fluid cement and casting it into a wafer mold. The mold is made in cope and drag style from two sheets of teflon (see Figure 5). A sheet of teflon impregnated fiberglass is placed between the cope and the drag in order to facilitate removal of the dried wafers. When the wafers are dried (green wafers) their densities are measured by a ballasted mercury submersion technique and then they are sintered. All sintering was accomplished by the same cycle,

Figure 4a. Nicrogap 108 braze sinter metal. 1000X

Figure 4b. Hastelloy C braze sinter metal. 1000X

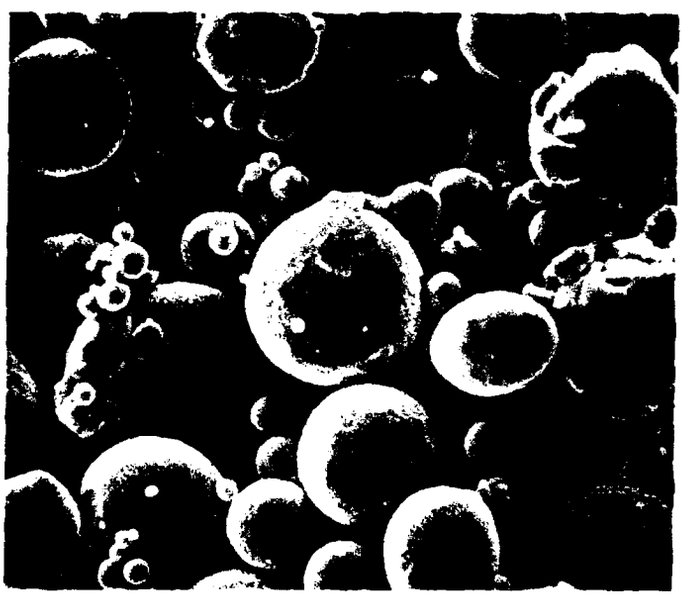


Figure 4c. René 80 braze sinter metal. 1000X

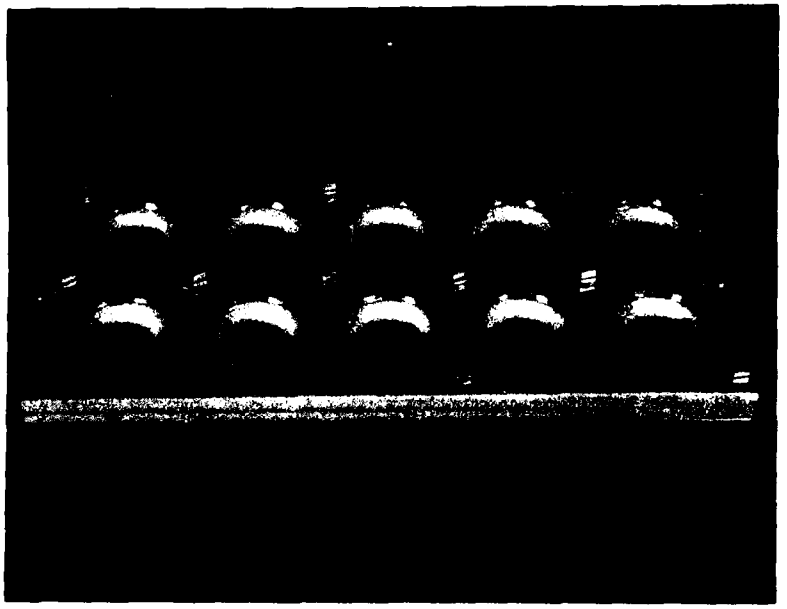


Figure 5. Assembled teflon mold for making pre-sintered wafers.

TABLE 1

NOMINAL CHEMICAL COMPOSITIONS OF THE BRAZE SINTER METALS AND THE BRAZE FILLER METALS

Material	Weight Percent of Elements (Balance Ni)							
	Cr	Fe	Co	W	Mo	Si	B	Other
Nicrogap 108	15	7	-	-	-	.75	.20	
Hastelloy C	17	6	-	5	19	-	-	
René 80	14	0.2	9.5	4	4	0.2	0.015	3 Al, 5 Ti
Nicrobraz 200	7	3	-	6	-	4.5	3.2	
AMI 4777 (BNi-2)	7	3	-	-	-	4.5	2.8	
AMI DF-3	21	-	21	-	-	-	2.9	3.5 Ta, .03 La
D-15	15.3	.5 max	10.3	.05 max	.05 max	-	2.3	3.5 Al, 3.4 Ta

i.e., heat in vacuum to 500°F, proceed to 700°F over a course of 1-hr, proceed further to 2065°F and hold for 1/2-hr. The slow heating in the 500 to 700°F range allows for the slow outgassing of the cements and thus provides unbroken wafers. After sintering, critical properties such as density and %-shrink were either measured or calculated. These results may be found in Table 2.

During the course of this study, it represented little additional effort to evaluate two specific types of cement. One type of cement, here chosen as Nicrobraz Cement Grade No. 500, is soluable in acetone and alcohol. As such it is relatively fast drying and allows little time for molding a braze sinter metal application. The secord type of binder, here chosen as Nicrobraz 'S' Binder, is water soluable, relatively slow to dry, and allows time for molding, pushing sinter metal into a crack, etc. In all sinter-filler metal combinations both the 500 and the S cement were used. When the braze filler metal was applied to the sintered wafer, the binder used was always the same as that used to make the sintered wafer.

In order to record the effects of partial sintering and the cements, a sintered wafer of Hastelloy C that had been bound by the S cement was broken. A 1000X photograph of the fractured surface may be seen in Figure 6. It may be noted that little if any evidence of residual cement can be seen. Furthermore, the points of sintering as well as those that were broken in the fracture are apparent.

2.3.2 Brazing of the Sinter Metal Wafers

All of the braze sinter metals, by use of both cements, were made into sufficient sintered wafers for brazing. All possible sinter metal-cement-filler metal combinations were investigated. The brazing cycles were as shown in Table 3

When the braze filler metal was added to the wafer, it was necessary to ascertain how much to apply. This was done by calculating the amount of filler metal required to just fill

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DEVELOPMENT AND EVALUATION OF WIDE CLEARANCE BRAZE JOINTS IN GA--ETC(U)
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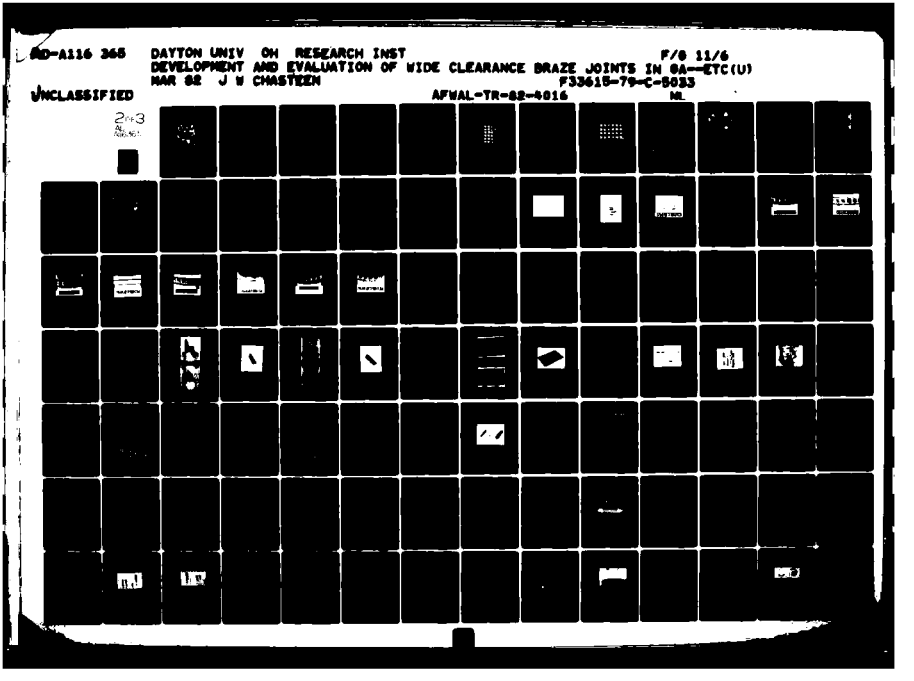

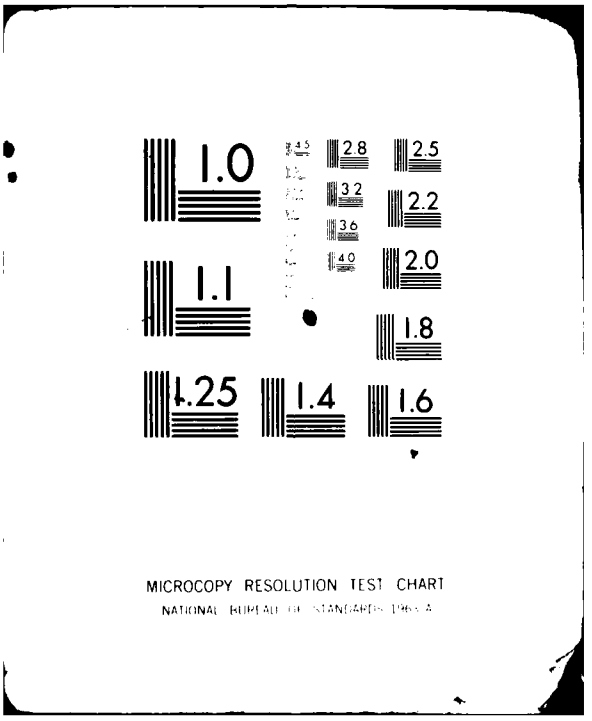
1.0
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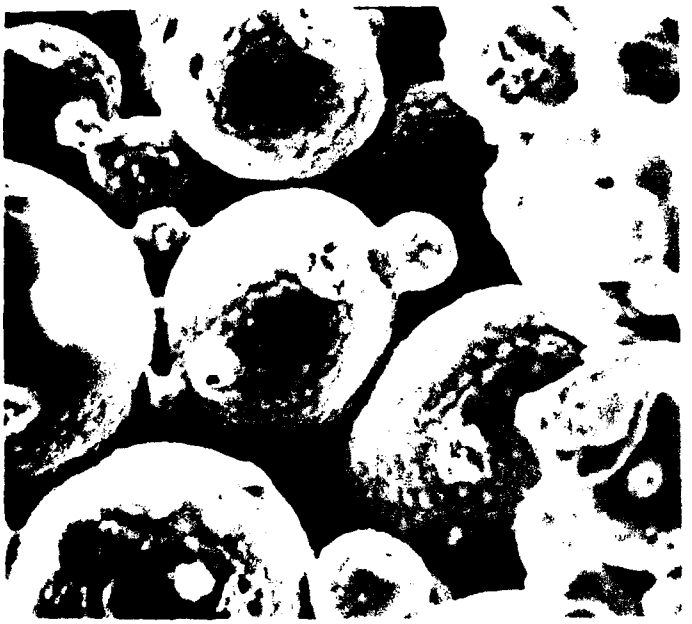


Figure 6. Fracture surface of a sintered Hastelloy C wafer. 1000X

TABLE 2

PERTINENT WAFER DATA

Cement	Sinter Metal	Green Wafers: Vol. (cc)	Green Wafers: Density ρ_G (g/cc)	Sintered Wafers: Vol. (cc)	Sintered Wafers: Density ρ_S (g/cc)	Sintered Wafers: Percent Shrink	Sintered Wafers: Percent Porosity	Brazed Wafers: Braze Filler Metal	Brazed Wafers: Weight of Braze Metal Applied (g)	Brazed Wafers: Vol. (cc)	Brazed Wafers: Density ρ_B (g/cc)	Brazed Wafers: Percent Shrink
S	N 108	1.83	4.3	1.44	5.42	21	35	N 200	4.3	1.38	8.32	3.96
S	N 108	1.86	4.15	1.46	5.17	22	39	BNi-2	4.6	1.58	7.28	-8.22
S	N 108	1.68	4.62	1.33	5.75	21	32	DF-3	3.5	1.29	8.35	3.15
S	N 108	1.68	4.7	1.34	5.78	20	32	D-15	3.4	1.27	7.95	5.23
500	N 108	1.53	4.93	1.24	6.05	18	28	N 200	2.9	1.23	8.31	0.54
500	N 108	1.38	4.95	1.12	6.02	19	29	BNi-2	2.6	1.18	7.72	-5.23
500	N 108	1.49	5.14	1.23	5.99	15	29	DF-3	2.9	1.17	8.32	4.77
500	N 108	1.45	4.95	1.19	5.98	18	29	D-15	2.8	1.14	8.12	4.33
S	Hast C	1.74	5.46	1.77	5.26	-2	41	N 200	5.95	1.84	8.17	-3.7
S	Hast C	1.75	5.30	1.81	5.04	-3	43	BNi-2	6.3	1.93	6.84	-6.7
S	Hast C	1.89	5.00	1.81	5.18	+4	41	DF-3	6.1	1.70	8.43	2.9
S	Hast C	1.86	4.93	1.71	5.32	+8	40	D-15	5.5	1.67	8.36	-2.2
500	Hast C	1.92	5.58	1.81	5.57	+6	37	N 200	5.5	1.95	8.29	-7.7
500	Hast C	1.62	5.68	1.78	5.80	+2	34	BNi-2	4.9	2.11	7.69	-18.3
500	Hast C	2.14	5.61	2.07	5.75	+3	35	DF-3	5.9	2.01	8.36	2.9
500	Hast C	1.98	5.64	1.91	5.82	+4	34	D-15	5.3	1.95	7.89	-2.2
S	R' 80	1.69	4.78	1.69	4.77	0	41	N 200	5.8	1.73	7.13	-2.57
S	R' 80	1.84	4.81	1.79	4.91	3.0	39	BNi-2	5.7	2.38	5.89	-32.7
S	R' 80	1.93	4.68	1.90	4.71	1.5	42	DF-3	6.5	1.86	8.02	1.86
S	R' 80	1.54	4.89	1.48	4.92	4.0	39	D-15	4.7	1.56	7.94	-5.53
500	R' 80	1.52	5.49	1.49	5.60	2.0	31	N 200	3.8	1.70	6.45	-14.4
500	R' 80	1.80	5.55	1.95	5.55	-7.0*	31	BNi-2	4.9	2.46	6.28	-26.1
500	R' 80	1.58	5.62	1.60	6.21	-1.0*	23	DF-3	3.1	1.59	8.00	0.8
500	R' 80	1.52	5.51	1.49	5.60	2.0	31	D-15	3.7	1.40	7.94	6.2

TABLE 3

BRAZING CYCLES

Braze Filler Metal	Time	Temperature
Nicrobraz 200	1/2 hr	2065°F (1130°C)
BNi-2	1/2 hr	1950°F (1065°C)
AMI DF-3	1/2 hr	2200°F (1200°C)
D-15	1/2 hr	2200°F (1200°C)

the pores of a wafer. In order to do this it was necessary to know the theoretical (zero porosity) density of the braze filler metal and the volume of the pores in a sintered wafer. In order to assess the latter, it was necessary to know the theoretical density of the braze sinter metal. Thus a 10 gm amount of each sinter metal and each filler metal was consolidated into a fully dense mass by melting in an inert gas arc button furnace. The densities of the resulting buttons were measured by the tungsten ballasted mercury submersion technique. The results of the measurements are listed in Table 4. The pore volume of a sintered wafer is readily calculated as

$$V_P = W_S\left(\frac{1}{\rho_S} - \frac{1}{\rho_S^{Th}}\right)$$

where V_P = pore volume in cc

W_S = wt. of the sintered wafer in gms

ρ_S = the density of the sintered wafer in g/cc

ρ_S^{Th} = the theoretical density of the braze sinter metal

The proper amount of braze filler metal to apply is then calculated by

$$W_B = \rho_B^{Th} V_P$$

where W_B = wt. of braze filler metal applied in gms

ρ_B^{Th} = the theoretical density of the braze filler metal

Figure 7 is a photograph of the resulting wafers which were brazed as described. The densities and other physical data may be found in Table 1.

Reference to Figure 7 will show that the Nicrogap 108 and the René 80 wafers when brazed with either AMI DF-3 or D-15 show evidence of melting. This prompted the investigator to suspect

TABLE 4

THEORETICAL DENSITIES OF PERTINENT BRAZE AND SINTER METALS

Metal	Density (g/cc)
Nicrogap 108	8.57
Hastelloy C	8.32
René 80	8.26
Nicrobraz 200	8.27
BNi-2	7.97
AMI DF-3	8.21
D-15	8.05

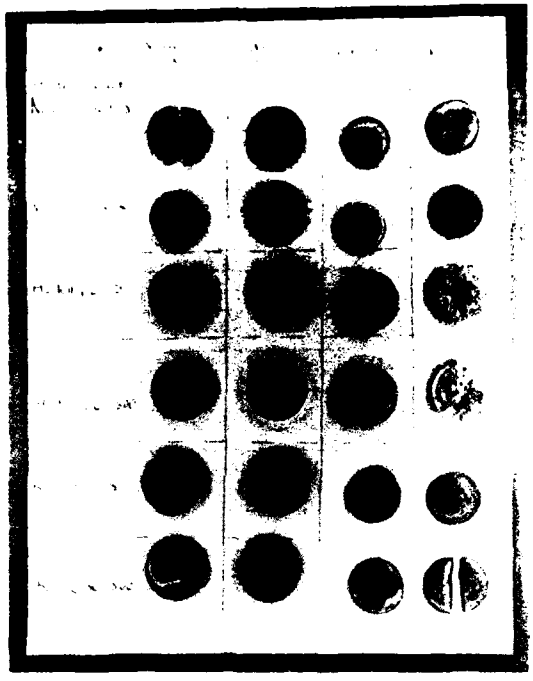


Figure 7. Brazed wafers resulting from all sinter-filler metal combinations.

that the brazing temperature for these gap filler combinations may be too high. Consequently, sufficient sintered wafers of Nicrogap 108 and René 80 were made to test brazing temperatures of 1150°C, 1175°C, and 1200°C for brazing 1/2-hr with AMI DF-3 and D-15. Figure 8 is a photograph of the results. The brazed wafers indicated that although 1200°C may be a bit high for brazing these combinations, 1175°C or below is too low. Thus the brazing cycles as listed in Table 3 remain in practice.

2.3.3 Metallography of the Brazed Filler-Sinter Metal Combinations

Reference to Figure 7 shows that the braze filler metal did not wet the braze sinter wafer when Nicrobraz 200 was applied to wafers made of either Hastelloy C or René 80. Neither were these wafers wetted by BNi-2 (AMI 4777) except, marginally, in the case where the Hastelloy C wafer was made with the water soluble 'S' binder. These sinter-filler combinations can thus be eliminated as potential combinations for making wide clearance butt joints.

The remaining wafers were halved and their cross sections were prepared for metallographic examination. Figures 9a through 9p are 100X magnifications of the microstructures. Each specimen was electroetched in a saturated $K_2Cr_2O_7$ solution at 4V for 10 sec. Alongside each figure a legend lists the wafer shrinkage upon sintering, the shrinkage upon brazing, and the brazed density. These values are significant in the final analysis and will be returned to in the discussion. The %-shrink is calculated by

$$\%\text{-shrink} = \left(\frac{V_I - V_{II}}{V_I} \right) \times 100$$

where V_I and V_{II} are the volumes of the wafer before and after the operation of interest respectively.

2.4 ANALYSES OF PHASE I RESULTS

The objective of Phase I was to determine the two braze filler metal-braze sinter metal combinations which were best suited for making wide clearance brazed butt joints in γ' alloys.

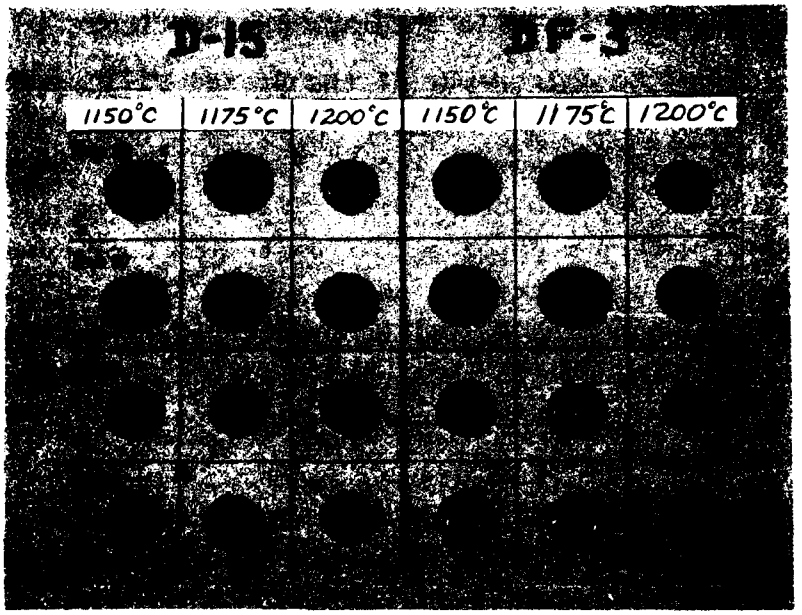
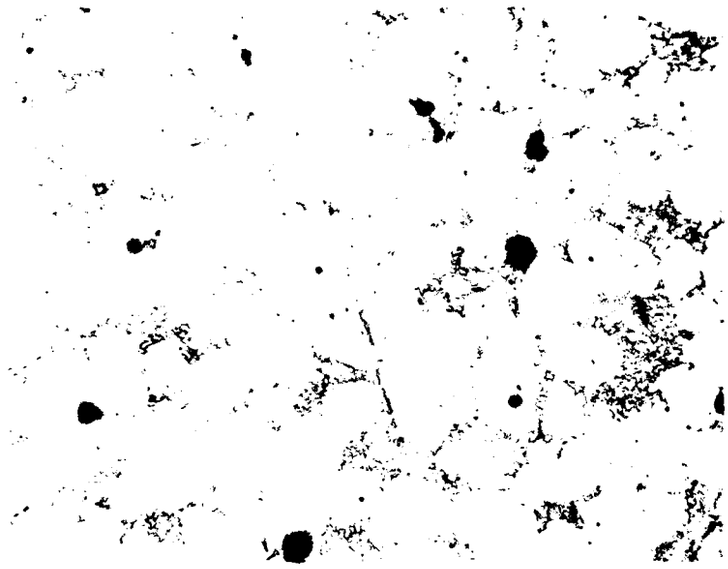
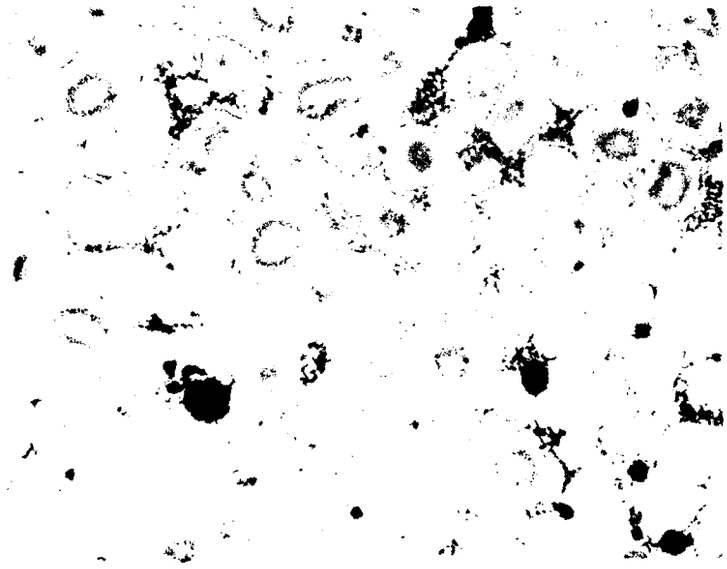


Figure 8. Brazed wafers showing various effects of brazing temperature.



% shrink on sintering	21
% shrink on brazing	3.96
brazed density	8.32

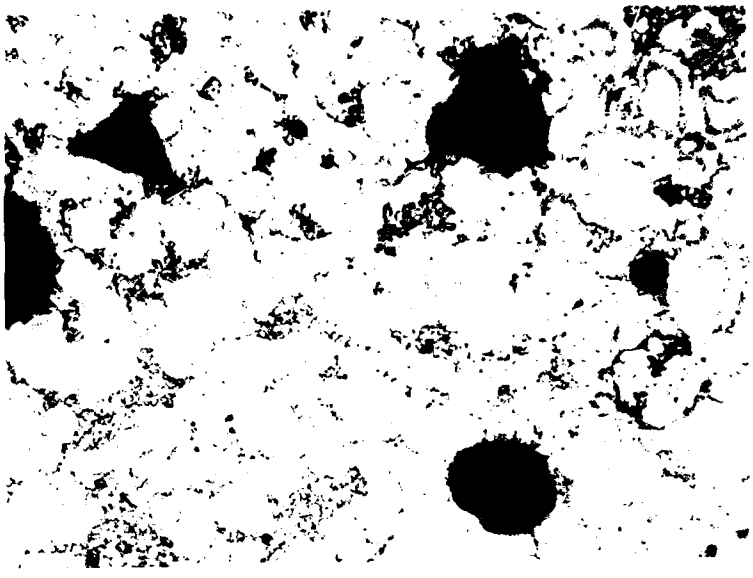
9a*. Brazed wafer of 108-S-200. 100X



% shrink on sintering	18
% shrink on brazing	0.54
brazed density	8.31

9b*. Brazed wafer of 108-500-200. 100X

*Combinations codes read: braze sinter metal-cement-braze filler metal where 108 = Nicrogap 108, C = Hastelloy C, R80 = René 80, S = Nicrobraz 'S' binder, 500 = Nicrobraz Cement No. 500, 200 = Nicrobraz 200, 4777 = AMI 4777 (BNI-2), and DF-3 = AMI DF-3.

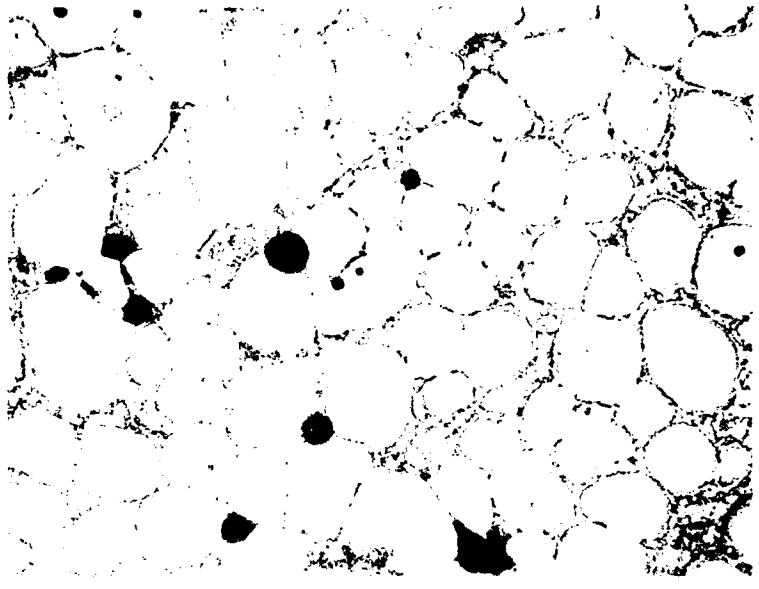


% shrink on sintering	22
% shrink on brazing	-8.22
brazed density	7.28

9c*. Brazed wafer of 108-S-4777. 100X

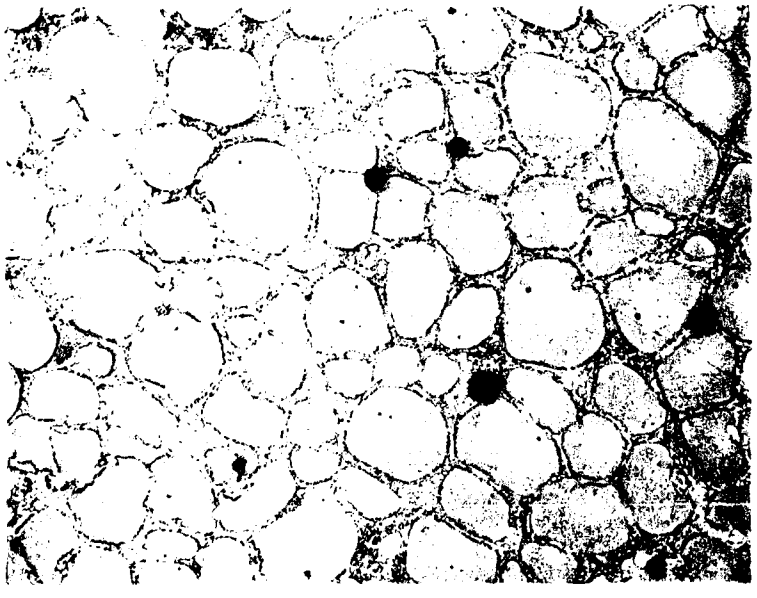
% shrink on sintering	19
% shrink on brazing	-5.23
brazed density	7.72

9d*. Brazed wafer of 108-500-4777. 100X



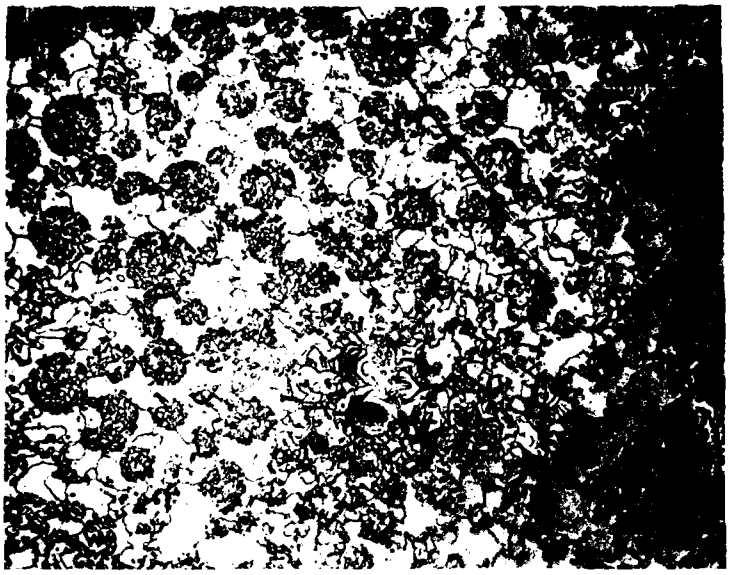
% shrink on sintering	21
% shrink on brazing	3.15
brazed density	8.35

9e*. Brazed wafer of 108-8-DF-3. 100X



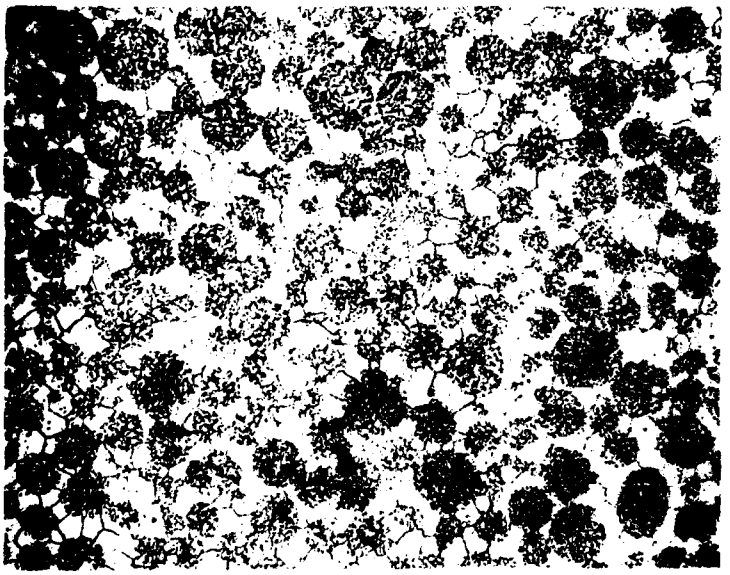
% shrink on sintering	15
% shrink on brazing	4.77
brazed density	8.32

9f*. Brazed wafer of 108-500-DF-3. 100X



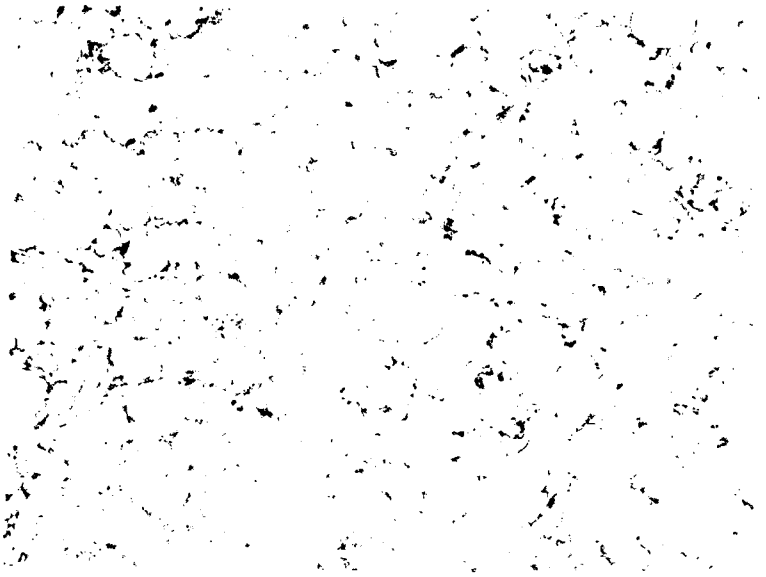
% shrink on sintering	4
% shrink on brazing	2.9
brazed density	8.43

9g*. Brazed [illegible] at [illegible]-DF-3. 100X



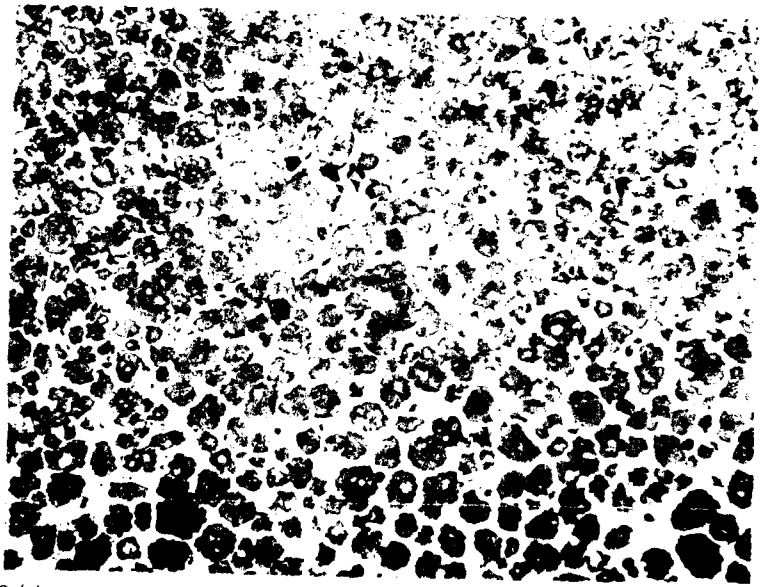
% shrink on sintering	3
% shrink on brazing	2.9
brazed density	8.36

9h*. Brazed with [illegible] at [illegible]-500-DF-3. 100X



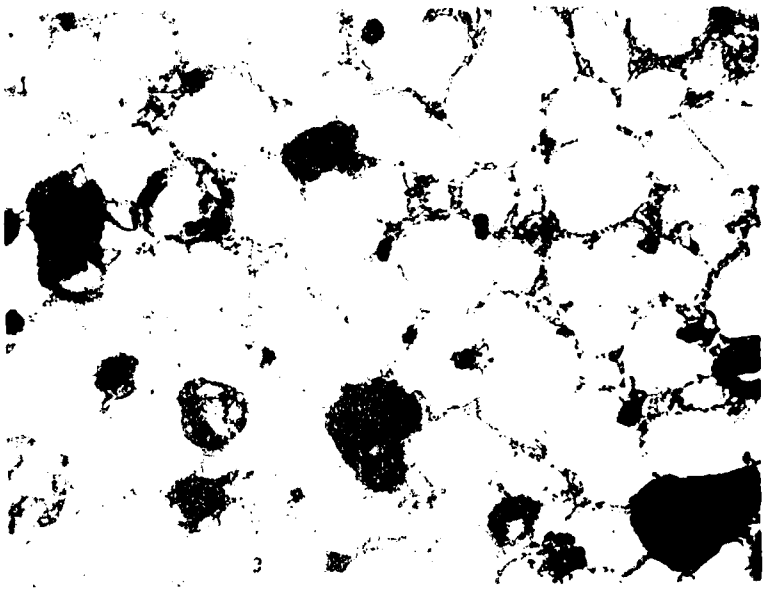
% shrink on sintering	1.5
% shrink on brazing	1.66
brazed density	g. 3

9i*. Brazed wafer of R80-S-DF-3. 100X



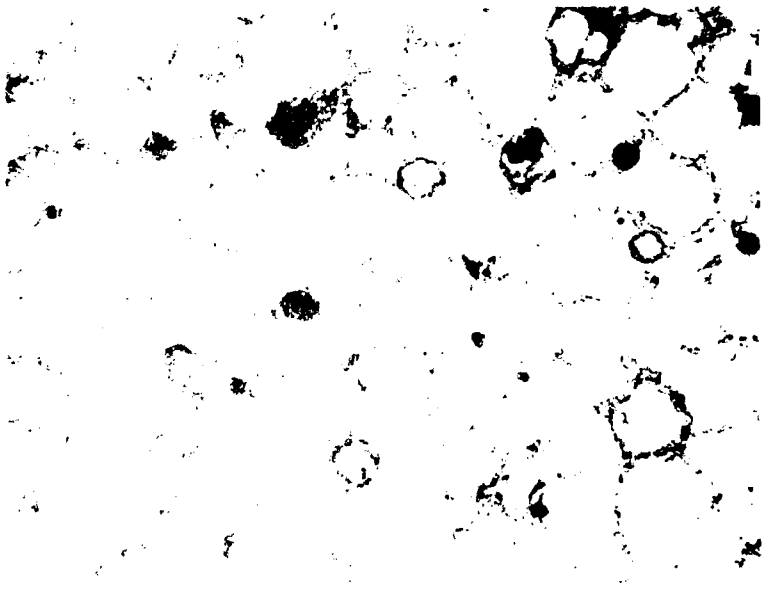
% shrink on sintering	-1.
% shrink on brazing	.-
brazed density	g.

9j*. Brazed wafer of R80-500-DF-3. 100X



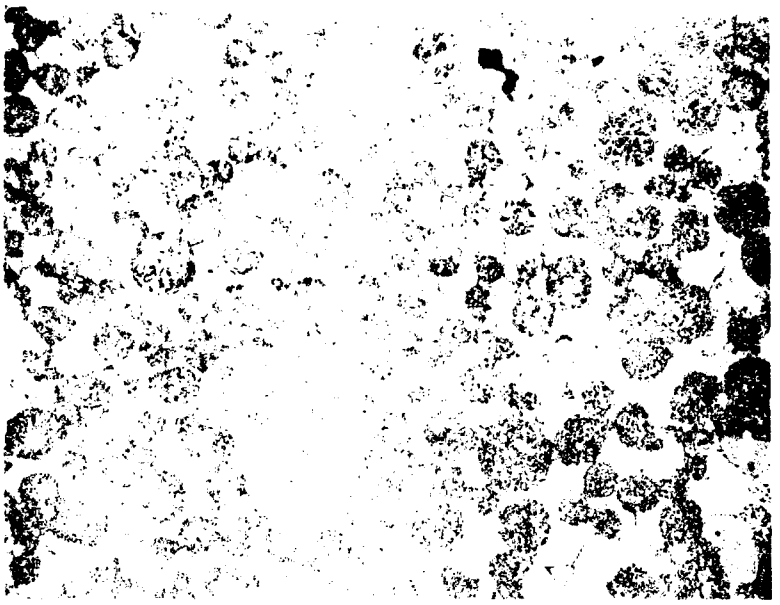
% shrink on sintering	20
% shrink on brazing	5.23
brazed density	7.[illegible]

[illegible]-8-D-1[illegible] 100X

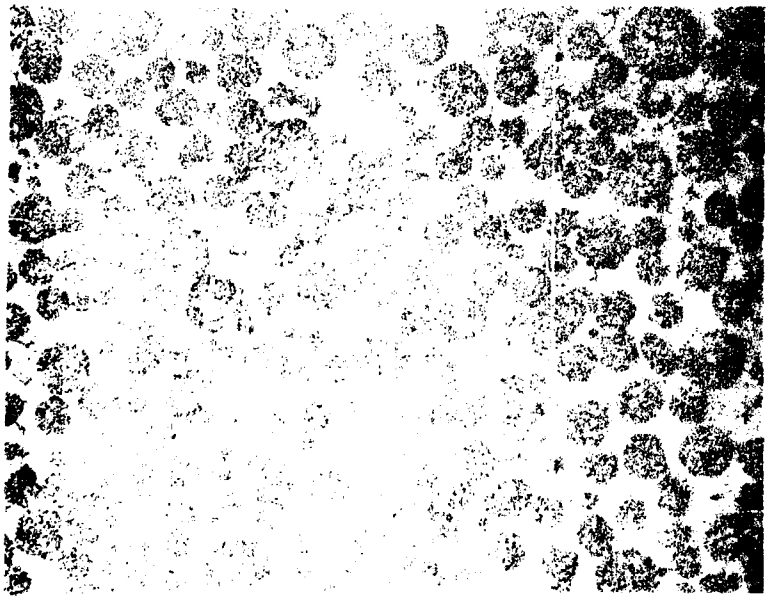


% shrink on sintering	18
% shrink on brazing	4.33
brazed density	8.12

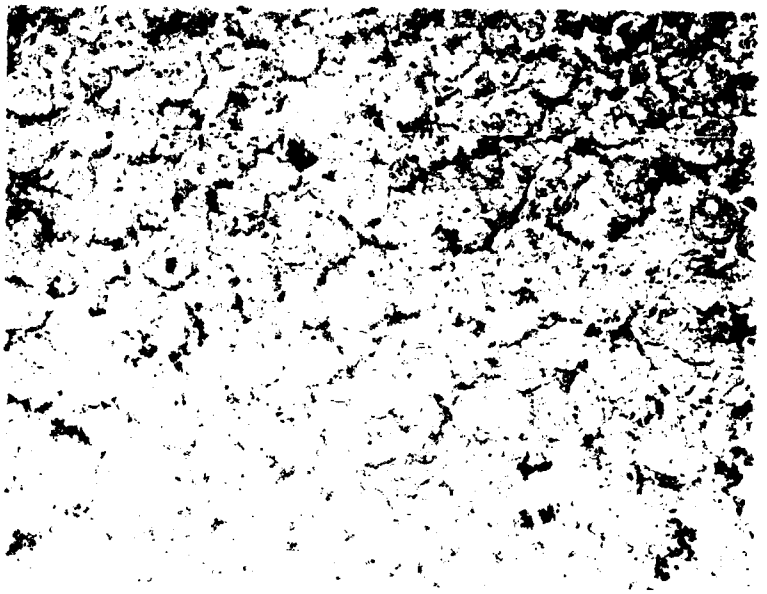
[illegible] 100X



% shrink on sintering	8
% shrink on brazing	-2.2
brazed density	8.36



% shrink on sintering	4
% shrink on brazing	-2.3
brazed density	7.89



% shrink on sintering	4
% shrink on brazing	-5.53
brazed density	7.94

9c*. Brazed wafer of R80-S-D-15. 100X

% shrink on sintering	3
% shrink on brazing	-4..
brazed density	7.94

9d*. Brazed wafer of R80-500-D-15. 100X

2.4.1 Analysis of Task 1

The filler metal-parent alloy compatibility study failed to delineate between the braze filler metal candidates in that they all wetted and filleted well for all γ' alloys tested when such alloys had been fluorocarbon cleaned. When these alloys had been pre-oxidized and grit blasted but not fluorocarbon cleaned, the brazing was, in general, unsuccessful. These data only corroborate the necessity of fluorocarbon cleaning which is planned for the test specimens anyway.

2.4.2 Analysis of Task 2

The sinter metal-filler metal compatibility study proved to be more delineating but still not clearly decisive.

2.4.2.1 The Cement and Binder

Comparison of Figures 9a through 9p by pairs generates a mild suspicion that brazed wafers made from the water soluble binder ('S') tend to have slightly higher porosity than those made from the alcohol soluble cement (500). This tendency, however, is neither all pervading nor profound. Although a strong tendency for %-shrink at the sintered stage would bode poorly for a cement or binder, reference to such data in Table 2 reveals no such tendency. Thus the evidence of this study, from a metallurgical point of view, shows the water soluble binder and the alcohol soluble cement to be equivalent.

In the making of wide clearance butt joints, it is convenient if the joint dries (sets-up) rapidly in order that the assembly can be moved. It is for this reason and this reason alone that the alcohol soluble cement will be used exclusively during the remaining course of this investigation.

2.4.2.2 The Sinter-Filler Combinations

Before proceeding with the analysis a qualifying word about the microstructures of Figures 9a-9p is in order. The microstructures of several of the brazed wafers were not uniform. The photomicrographs of Figures 9a-9p are chosen

from that area of the wafer which the investigator felt was representive of a uniform microstructure that could be achieved with a slight technique development effort. It also needs be reported that past experience with the wafer compatibility evaluations dictates the following observations: (1) if the braze filler metal will not wet and fill the wafer, that combination will not make a brazed joint, (2) if the braze filler metal does wet and fill the wafer, that combination will make a brazed joint, but (3) when the braze filler metal marginally wets and fills the wafer, that combination is adequately tested only by making joints. With these observations in mind, only those combinations whose microstructures are not shown may be eliminated at this point in the study.

A high degree of shrink upon sintering is an undesirable characteristic for a braze sinter metal. This characteristic is displayed by Nicrogap 108 (see Table 2). However, it is desirable to have a high temperature and a moderate or low temperature braze filler metal in the final two sinter-filler combinations. Therefore, although combinations involving Nicrogap 108 with AMI DF-3 or with D-15 may be eliminated, those with Nicrobraz 200 and BNi-2 (AMF 4777) cannot.

Figures 9a-9p show that combinations of Hastelloy C and René 80 with both AMI DF-3 and D-15 result in brazed microstructures where the matrix phase is solid solution (and probably high melting) with the original sinter metal particles in suspension while dissolving. This is not the case for the combination of Nicrogap 108 with the high temperature brazes. This fact alone would have eliminated the Nicrogap 108 for these brazes if the shrink criterion had not.

2.4.2.3 Conclusion

The butt joint making combinations that remain viable are:

Cement	Sinter Metal	Filler Metal
Nicrobraz 500	Nicrogap 108	Nicrobraz 200
Nicrobraz 500	Nicrogap 108	BNi-2
Nicrobraz 500	Hastelloy C	AMI DF-3
Nicrobraz 500	Hastelloy C	D-15
Nicrobraz 500	René 80	AMI DF-3
Nicrobraz 500	René 80	D-15

One combination will be chosen from the first two and one from the last four.

The next most obvious way to delineate between the remaining candidate combinations is to make and evaluate butt joints. Such joints are currently being made and will be evaluated on the basis of their integrity. If this fails to delineate best combinations, a decision will be made on the basis of which joint, from a metallurgical point of view, is likely to display the best combination of mechanical properties.

SECTION 3

ADDITIONAL EFFORT: BRAZE REPAIR OF TWO AUXILIARY POWER UNIT TURBINE NOZZLES

As an added effort AFML personnel requested the UDRI Fluorocarbon Cleaning process be employed in the braze repair of two APU nozzles. A third nozzle was supplied and sacrificed in order to determine the necessary process parameters. Figure 10 is a photograph of an as-received nozzle; it also shows the manner in which the sacrificed nozzle was sectioned. The two remaining nozzles were of parts types GTC 85-71A and GTCP 85-397. The nozzles were each about 12-inches in diameter and 8-inches high. Since their size precluded preparation in the UDRI laboratory facility, the parts were ultimately fluorocarbon cleaned in the 19-inch diameter pilot retort.

The nozzles were grit blasted and then suspended on a fixture tree before placing in the cleaning retort. Figure 11 shows the fixturing assembly; the three nozzle segments at the top were included to simulate a full pilot load and have no other significance in this effort. The nozzles were thus fluorocarbon cleaned.

The cleaned nozzles were then braze repaired and braze built-up where required. The nozzles were quite similar and behaved identically. Thus only one of them will be fully documented here. Some general comments on the braze repair are in order. APU nozzles are typically withdrawn from service beacuse hair line cracks develop at both the leading and trailing edges of the airfoils where the airfoils join both the upper and lower bands. Such cracks are repaired by area brazes which are applied without regard to whether there is a crack at the point. In some cases leading edge erosion is prevalent on most of the airfoils. Such areas must be built-up prior to final brazing. This condition existed in the GTC 85-71A nozzles; the erosion was mild, and its extent may be seen in Figure 12. Because of the leading edge build-up requirement it is this part that will be documented.

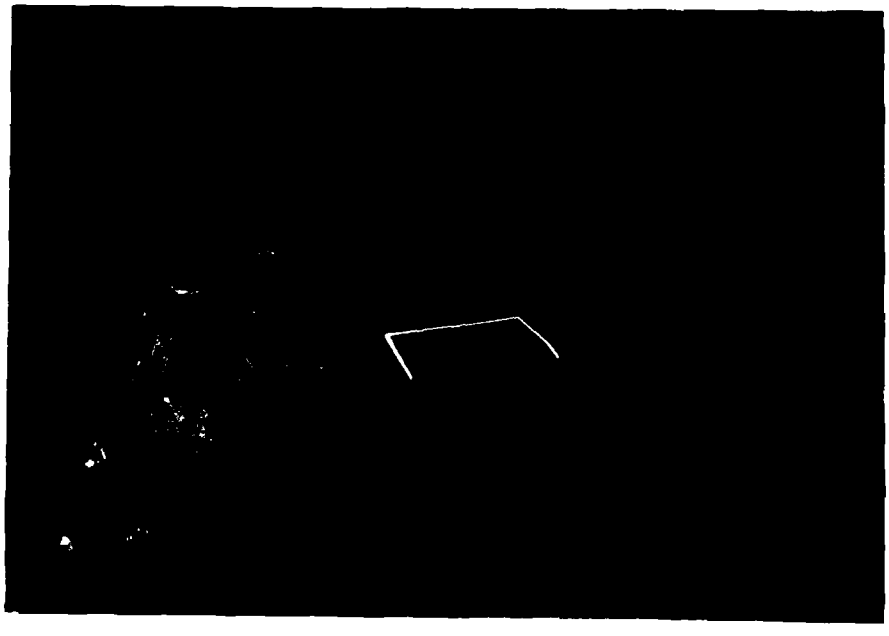


Figure 10. An APU nozzle as-received from service.

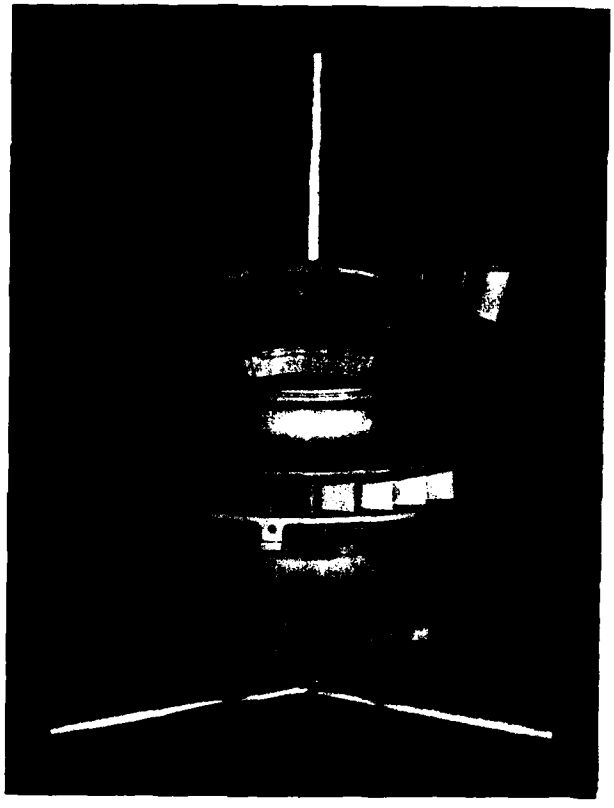


Figure 11. Fixture tree assembly of parts as they were placed in the fluorocarbon cleaning retort.

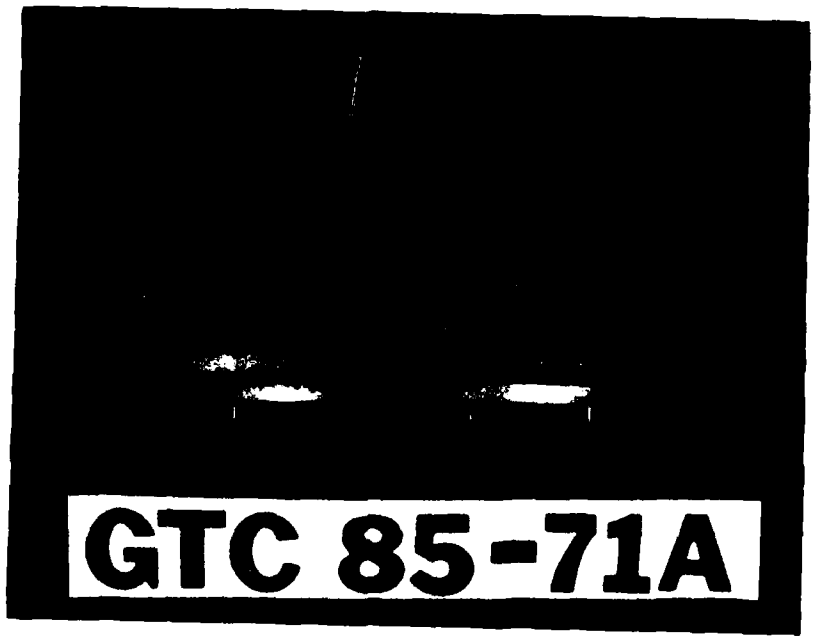


Figure 12. An APU nozzle showing leading edge erosion.

The leading edges were built-up by applying a 2:1 mixture of Nicrogap 108 and Nicrobraz 200 suspended in Nicrobraz Cement No. 500. The mixture was applied by layers dropped on with an eyedropper. The dried green deposits were then dressed with an abrasive cloth and made to conform to the blade contour. This assembly was then brazed in vacuum at 2065°F for 1/2 hr. The result of this operation is shown in Figure 13. The edges were then mechanically dressed (see Figure 14) and the area brazes were applied. These were brushed on from a suspension of Nicrobraz 200 in Nicrobraz Cement No. 500 thinned with acetone. Area braze was applied to the other nozzle as well. Photographs of the nozzles at this stage of repair are presented in Figures 15 and 16.

Figures 17 and 18 show the leading edges of the nozzles after brazing in vacuum at 2065°F for 1/2 hr. Figure 17 shows that the leading edges have been restored and that the braze has quite successfully wet the casting. Figure 18 shows similar results for the GTCP 85-397 part; it also shows some area braze touch up on the throat of the nozzle. This was necessary because casting dross which had been entrapped was removed by the fluorocarbon cleaning leaving areas of small pits. As a matter of documentation, Figures 19 and 20 show the trailing edges of the brazed airfoils. What appear to be cracks in the GTC 85-71A airfoils are actually casting laps; the cracks have been healed.

Both the GTC 85-71A and the GTCP 85-397 nozzles have been returned to AFML personnel for their dispensation.

Figure 13. The nozzle of Figure 12 after initial build-up.

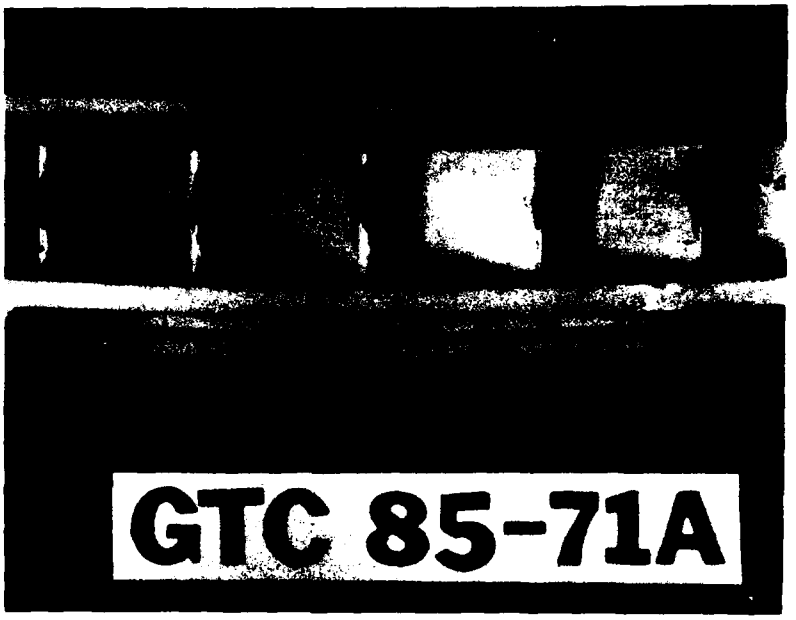


Figure 14. The nozzle of Figure 12 after dressing of the built-up areas.

Figure 15. The nozzle of Figure 14 after application of the area brazes.

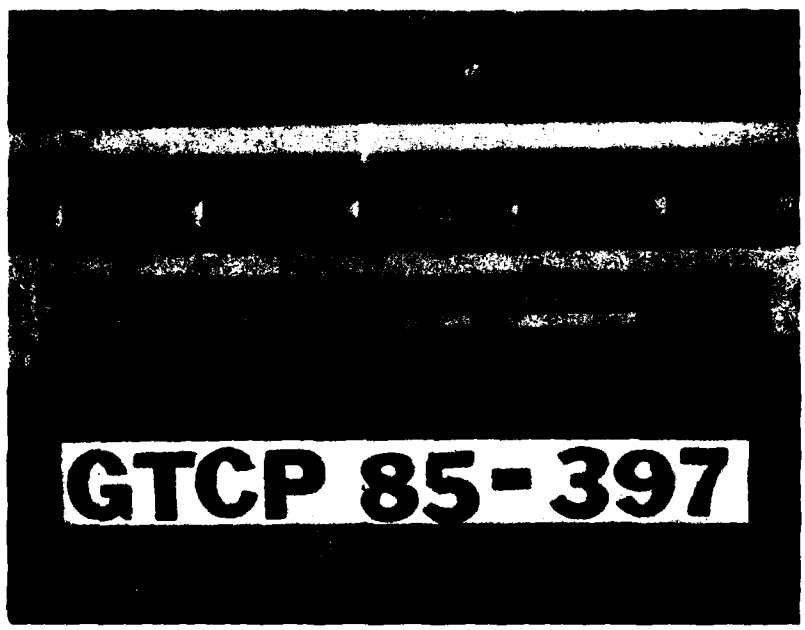


Figure 16. Same as Figure 15 but a different nozzle.

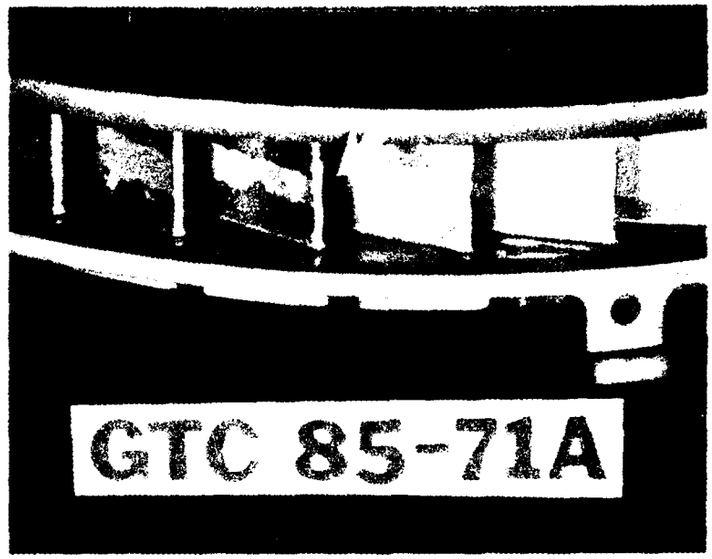


Figure 17. Leading edges of the braze repaired GTC 85-71A nozzle.

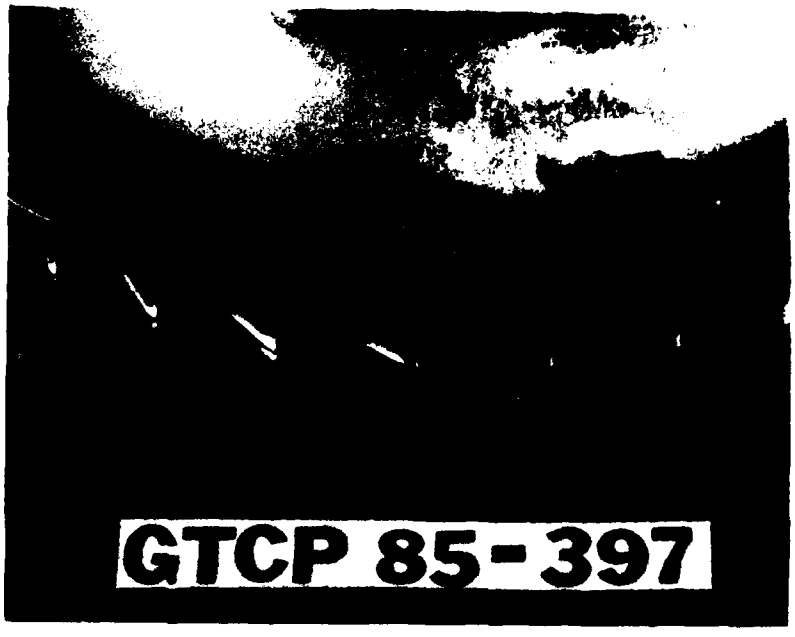


Figure 18. Leading edges and throat area after braze repair of the GTCP 85-397 nozzle.

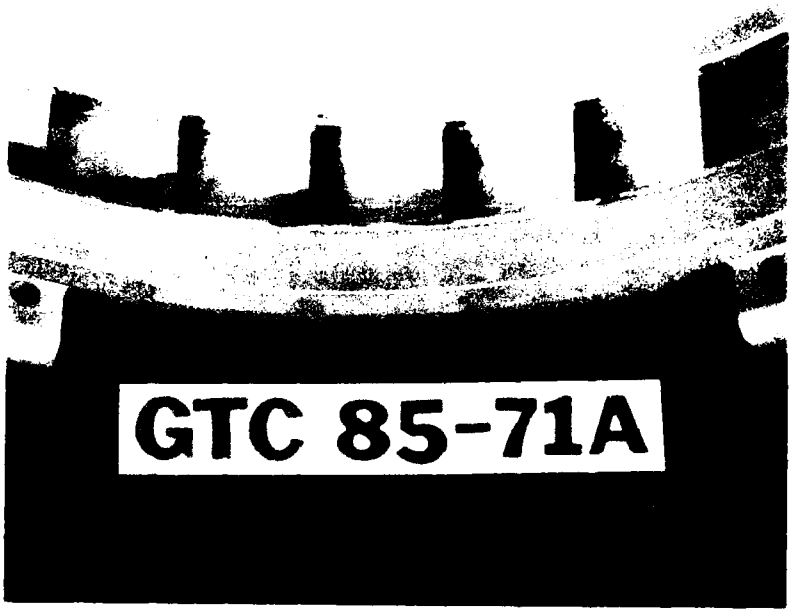


Figure 19. Trailing edges of the nozzle of Figure 17.

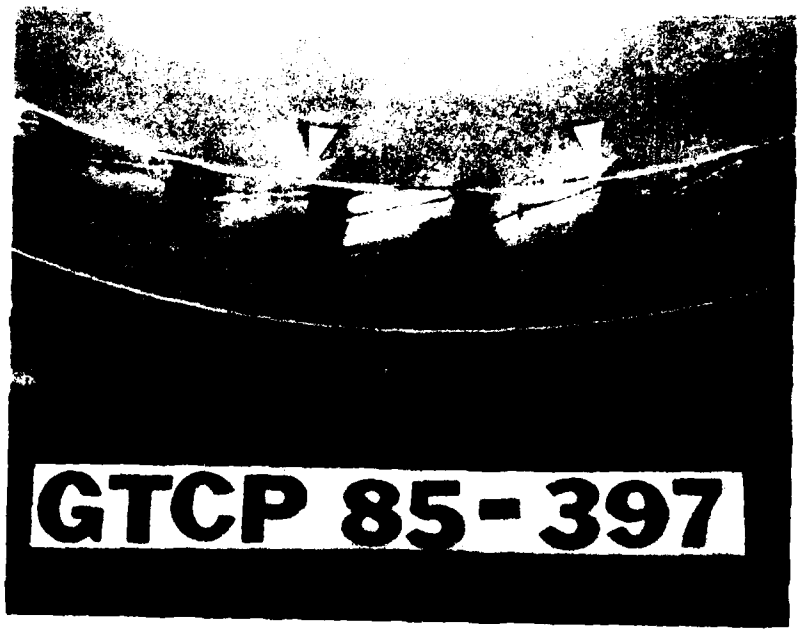


Figure 20. Trailing edges of the nozzle of Figure 18.

SECTION 4

LIST OF REFERENCES

1. "Engineering Properties of Alloy 713C," International Nickel Co., Inc., Nov. 1968, p. 6.

2. "Brazing of Hastelloy X with Wide Clearance Butt Joints," Technical Report AFML-TR-79-4026, March 1979.

3. Chasteen, J. W. and Metzger, G. E., "Brazing of Hastelloy X with Wide Clearance Butt Joints," Welding Jrnl., 58, 4, April 1979, pp. 111-s – 118-s.

ADDENDUM 2

INTERIM TECHNICAL REPORT NO. 2

DEVELOPMENT AND EVALUATION OF WIDE GAP BRAZE JOINTS IN GAMMA PRIME ALLOYS

CONTRACT F33615-79-C-5033

INTERIM TECHNICAL REPORT

No. 2

30 May 1980

J. W. Chasteen

University of Dayton
Research Institute
Dayton, Ohio 45469

FOREWARD

This Interim Technical Report covers the work performed under Contract No. F33615-79-C-5033 during the period February 1, 1980 to June 1, 1980. It is published for information and the conclusions herein are those of the contractor alone.

This contract, with the Welding and Joining Group of the University of Dayton Research Institute, was initiated under the title "Development and Evaluation of Wide Gap Braze Joints in Gamma Prime Alloys." The work is being administered under the technical direction of Dr. G. E. Metzger of the Air Force Materials Laboratory, Metals and Ceramics Division, Wright-Patterson Air Force Base, Ohio.

The program is being directed by Dr. A. E. Ray, Project Supervisor, Metals and Ceramics Division. The principal investigator is Dr. J. W. Chasteen of the Welding and Joining Group.

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LIST OF ILLUSTRATIONS

*Joint composition and condition code: Braze Sinter Metal/Braze Filler Metal/Metallurgical History.

LIST OF ILLUSTRATIONS (CONTINUED)

UNIVERSITY OF DAYTON
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SECTION 1
INTRODUCTION

The first few turbine stages of advanced gas turbine engines must operate at temperatures which exceed the safe operating levels for stainless steels and solid solution superalloys. Engine components for these stages are often made from γ' hardened nickel base superalloys. Such components have become rather intricate in the air cooling techniques used and in their assembly (mechanical and brazed). Until recently, braze assembly of such components was marginal, and the technology for braze repair of such parts, upon retirement from service, was limited. The fluorocarbon cleaning process recently developed at UDRI now makes possible routine assembly and repair of γ' alloy engine components by standard nickel brazing techniques.

The physical properties of brazed joints and particularly wide clearance brazed joints have long been questionable. Consequently, welding is conventionally employed for assembly and repair of gas turbine engine components. Welding, however, has limitations in that it is a piece-by-piece, as opposed to a batch, operation and also it may not be possible to physically access the joint with a welding torch. In addition to these limitations, it is generally not possible to weld (or even braze) gamma prime type alloys by heretofore known art. As aforementioned, it has become possible to nickel braze gamma prime type alloys, even after service, if they are prepared by fluorocarbon cleaning prior to brazing. Since brazing is now available for such metallurgical systems and welding is still not an option, it is advisable to determine the physical properties of wide clearance nickel brazed joints in gamma prime alloys.

Such determinations are currently being conducted at UDRI under the auspices of USAF Contract No. F33615-79-C-5033, titled

"Development and Evaluation of Wide-Gap Braze Joints in γ' Alloys." What follows is an interim report on the first phase of the subject effort.

SECTION 2
PHASE 1: BRAZE-JOINT COMPOSITE

At the conclusion of the first interim report Phase 1 had been left incomplete. Task 1 of Phase 1 which demonstrates the compatibility of nickel brazes with fluorocarbon cleaned γ' alloys was lacking such demonstration for coated alloys that had been stripped and then cleaned. Task 3 was lacking a clear choice of the two braze sinter-braze filler metal combinations to use for the testing phases of the program. These tasks are now complete.

2.1 TASK 1. COMPATIBILITY OF BRAZE FILLER METALS WITH THE PARENT ALLOYS

Many gas turbine engine components that are made of γ'-type alloys are subjected to an oxidation-sulfidation protective coating prior to service. Wide clearance cracks which form in such components during service are subject to nickel braze repair after fluorocarbon cleaning. It was therefore a part of this effort to evaluate the compatibility of braze filler metals with the subject parent alloys after such alloys had been coated, stripped, and fluorocarbon cleaned.

Five T-bars each of Mar M 246, Inconel X-750, and Alloy 713C were coated with Alpak. The coating was accomplished by Wall Colmonoy Corp. according to standard procedures specified by the process owner. The coatings were thermally diffused at UDRI at 2100°F for 4 hrs. followed by air cool and grit blasting. Figures 1a-1c are photographs of the coated T-bars.

The coating was stripped from all T-bars by use of a stripping agent designated ASC 2-N according to procedures specified by the vendor (Alloy Surfaces Co., Inc.). Figures 2a-2c are representative photographs of the stripped T-bars. All T-bars were then fluorocarbon cleaned and subjected to run tests as previously described (Interim Technical Report No. 1).

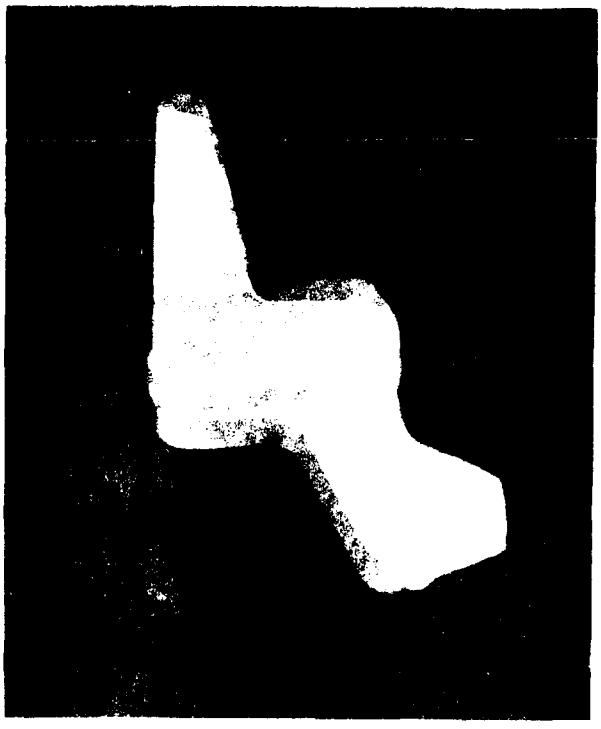

Figure 1a. [illegible]

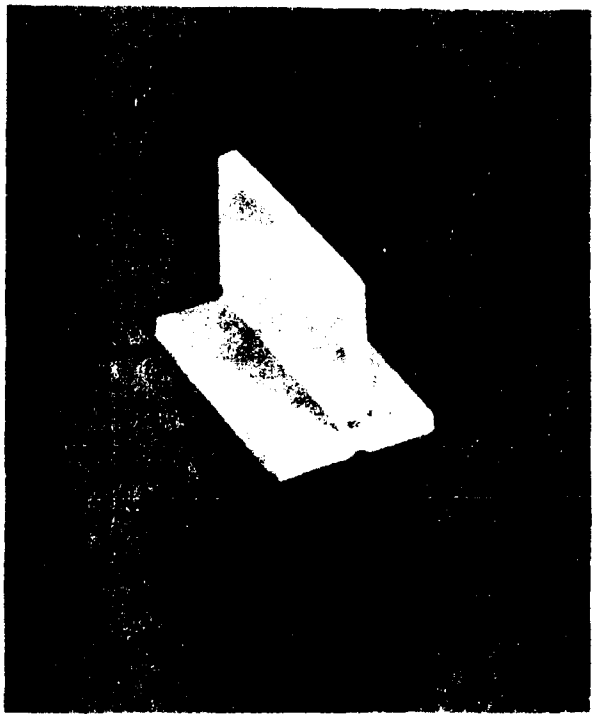

Figure 1b. [illegible]

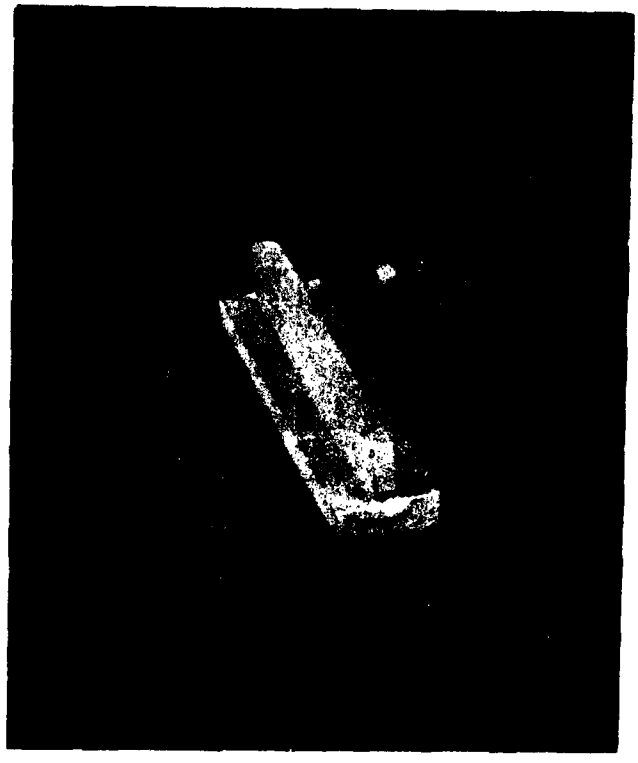

Figure 1c. Alloy 713C T-bar with Al-Si coating.

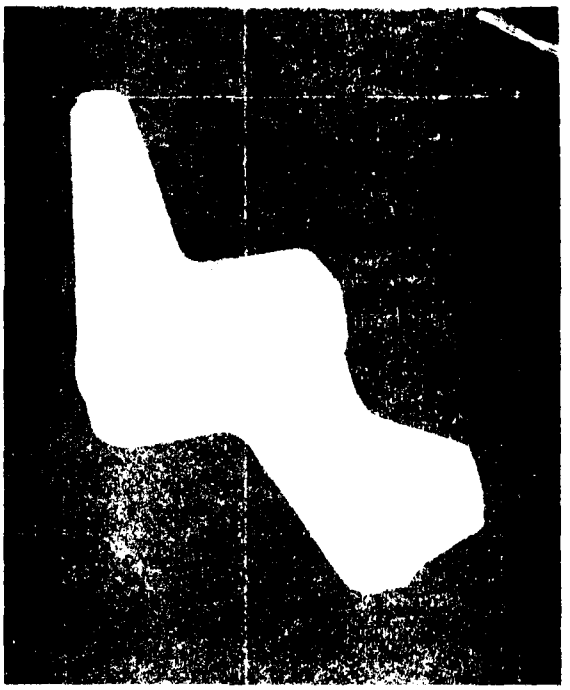

Figure 2a. Mar [illegible] Aljak coating.

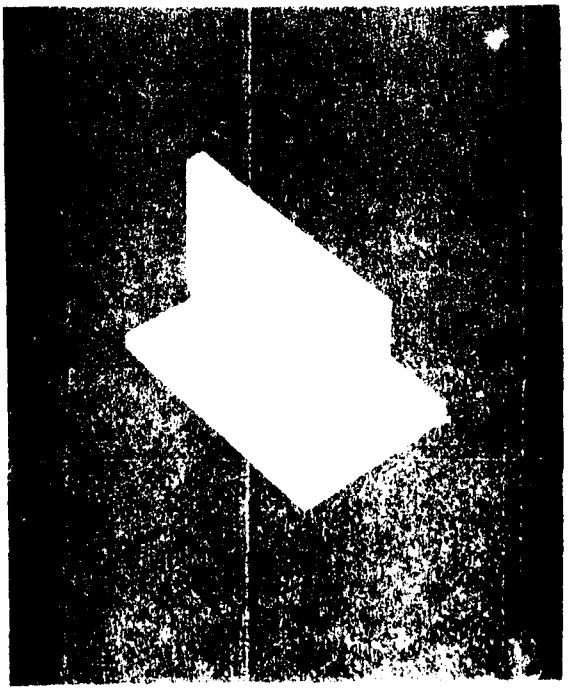

Figure 2b. [illegible] Aljak coating.

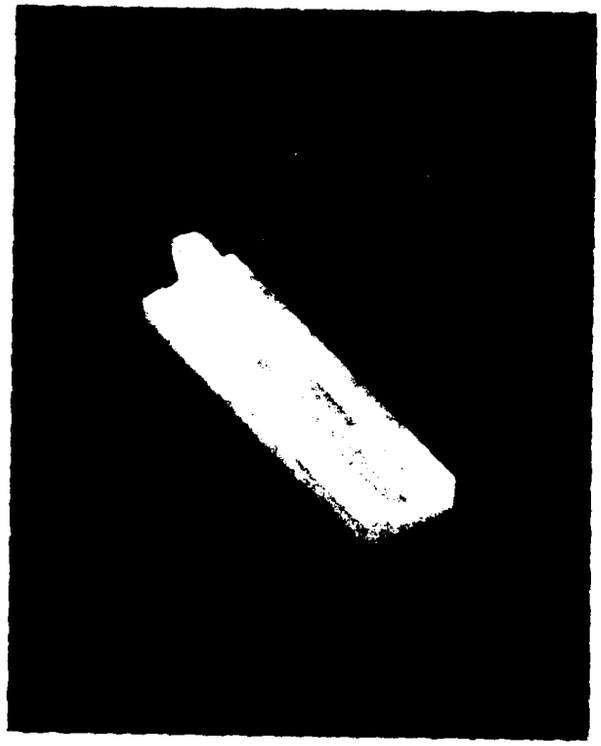

Figure 2c. Alloy 713C T-bar after stripping of Alpak coating.

The set-up, description, and results of the run tests may be seen in the photographs of Figures 3a-3c. For all alloys, the braze run was complete on the braze side. The fillet sides of the T-bars (Figure 3c) show a complete success rate in the case of Alloy 713C for all braze filler metals. The fillet sides of the X-750 and Mar M 246 T-bars are somewhat marginal. In the opinion of the investigator, lack of abundant fillets, where they occur, are probably explained by either extremely tight clearances or residual Alpak coating in the T-bar joints. It is likely that any of the four braze filler metals is readily compatible with any of the three parent alloys which have themselves been coated, stripped, and fluorocarbon cleaned.

2.2 TASK 2. COMPATIBILITY OF BRAZE FILLER METALS WITH THE BRAZE SINTER METALS

This task is completed and was reported in the first interim report.

2.3 TASK 3. SELECTION OF BRAZE SINTER AND BRAZE FILLER METAL COMBINATIONS

The wafer studies failed to clearly delineate the best braze sinter-braze filler metal combinations. As a consequence, six combinations remained viable candidates, and it was decided to make and evaluate butt joints of alloy 713C bars by use of each of the candidate combinations. The candidate combinations were:

Sinter Metal	Filler Metal	Quick Code
Nicrogap 108	Nicrobraz 200	108/200
Nicrogap 108	BNi-2	108/4777
Hastelloy C	AMI DF-3	C/DF-3
Hastelloy C	D-15	C/D-15
René 80	AMI DF-3	80/DF-3
René 80	D-15	80/D-15

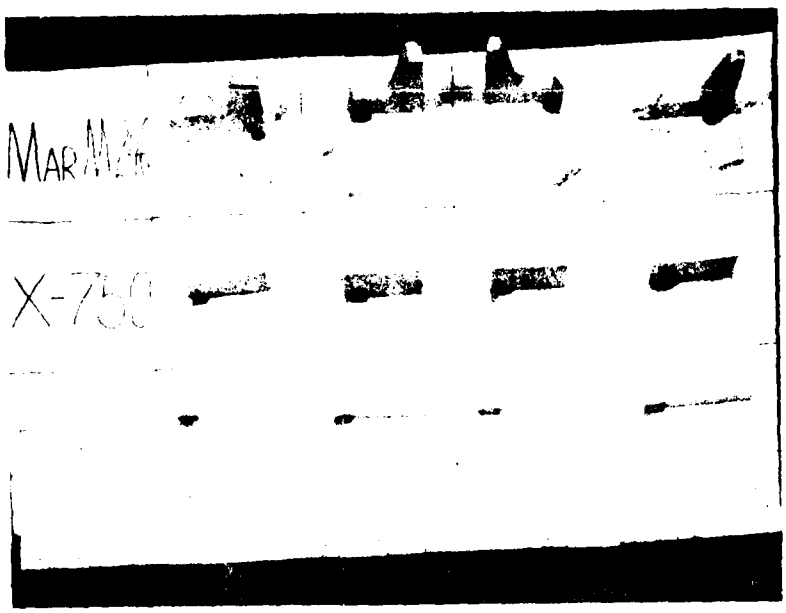

Figure 3a. All alloy T-bars after [illegible] cleaning and just prior to brazing.

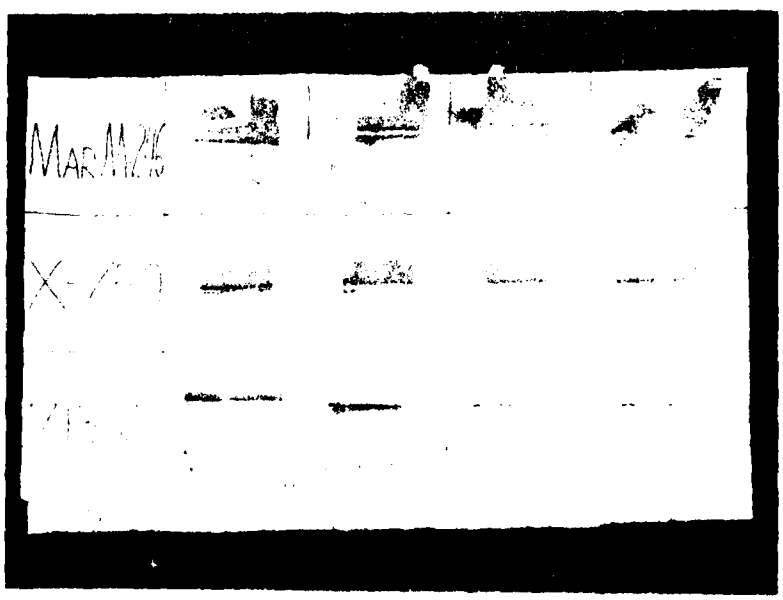

Figure 3b. Braze [illegible]

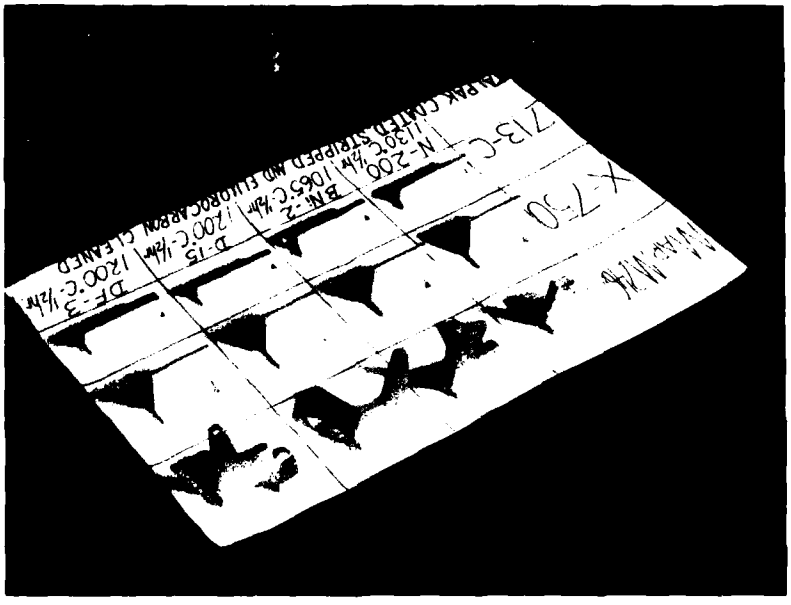

Figure 3c. Fillet side of the T-bars after brazing.

2.3.1 Making of Butt Joints

The bars which were used for this study were cut from extruded stock of Alloy 713C which had been provided by the Processing Group of AFML. The bars were cut to 2 1/2-inch lengths so that, when joined by butt joining, two of them constituted a tensile test specimen blank.

In order to simulate a brazed joint in a cracked engine component, the tensile blank bars were pre-oxidized in air at 1700°F for 16 hrs. The oxidized bars were then grit blasted and fluorocarbon cleaned. Butt joints were formed by a Nicrobraz 500 cement slurry with the braze sinter metal. Joint thicknesses were controlled and measured by use of a grooved fixture with a depth micrometer (see Figure 4). When a green joint was completed, it was slid into a grooved fixture (see also Figure 4) and allowed to dry. When drying was complete and the total bar had some green strength, it was transferred to a vertical holding fixture for sintering (see Figure 5). Also seen in Figure 5 are small pieces of nickel foil which were spot welded to the lower half of the bar after sintering. These pieces become holding rests for the braze filler metal feeding ring. The feeding rings are made of stainless steel and are, geometrically, the solid remaining when a short right cylinder is intersected by a right circular cone (see Figure 6). When the ring is placed upon the nickel stops, it provides a feeder well for the sintered butt joint which is fed by the molten filler metal at all points on its periphery. Figure 6 shows two completed brazed bars as they are placed in the vertical fixture and with their feeder rings still on.

This then is the method by which the butt joints have been and will be made. The technique was first developed and reported by G. E. Metzger.[1] All joints of this study were of a 15-mil clearance.

Figure 4. Brazed butt joint making fixture.

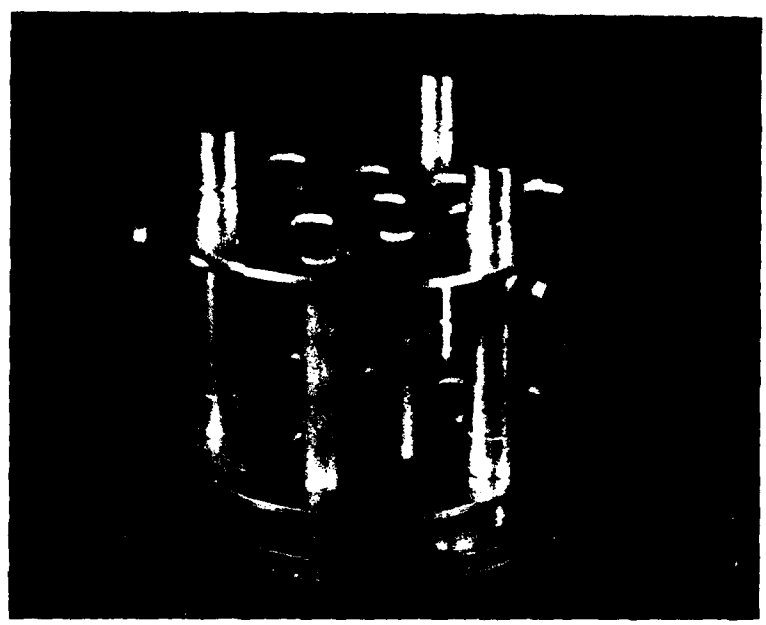

Figure 5. Jig for sintering butt joints for eventual brazing. Photo shows placement of joined bars and Ni tab stops for holding filler ring.

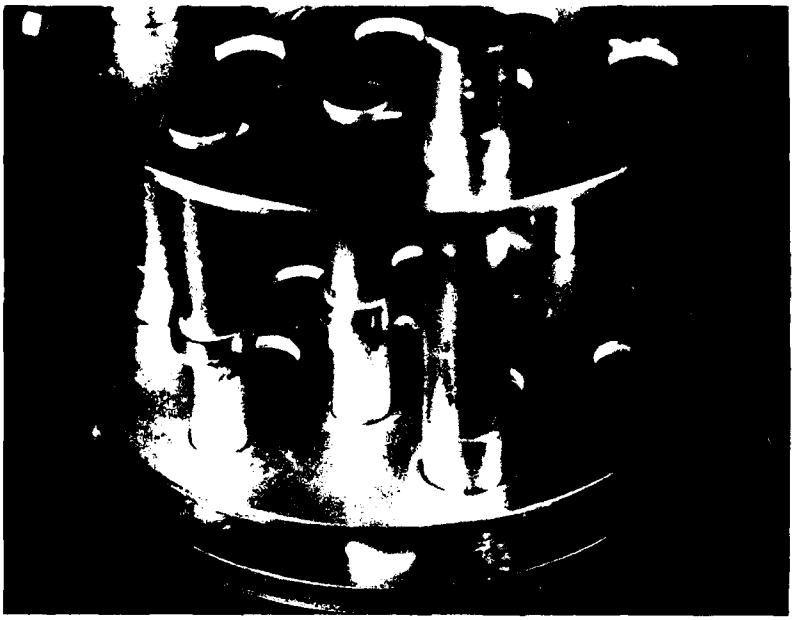

Figure 6. Same jig as in Figure 4 but showing brazed joint including filler ring.

2.3.2 Evaluation of the Butt Joints

2.3.2.1 Processing of the Butt Joints

One butt joint was made by use of each of the candidate sinter-filler combinations. The joints were then cut out of the bars and sectioned in two along a diameter. One half section was then prepared metallographically and the other was heat treated.

The heat treatment for improving stress rupture properties in Alloy 713C is: 2150°F 2 hrs. AC, 1700°F 16 hrs. AC.[2] The remaining half section of the subject joint were subjected to his treatment and then prepared metallographically. The metalographic results of the joint preparations may be seen in Figures 7 through 12.

2.3.2.2 Butt Joints: Discussion and Conclusions

2.3.2.2.1 Discussion

The butt joints which were made with the relatively low melting braze filler metals, namely, Nicrobraz 200 and BNi-2 (see Figures 7 and 8) display a multiphase matrix. Such a condition is characteristic of brittleness and should be avoided. These combinations also show a rather high porosity and, more alarmingly, the pores tend to concentrate at the joint-parent metal interface. The latter is likely to indicate a weak joint. When the heat treatment was applied to these joints (see Figures 7b and 8b) no appreciable homogenization was observed in the 108/200 joint. In the case of the 108/4777 joint the matrix actually melted and ran out, Figure 8b. The 108/4777 joint cannot withstand the solution and age heat treatment. Therefore neither of these sinter-filler combinations is a good choice for the physical properties measurements portion of this effort.

The other four combinations, namely C/DF-3, C/D-15, 80/DF-3, and 80/D-15, all show good

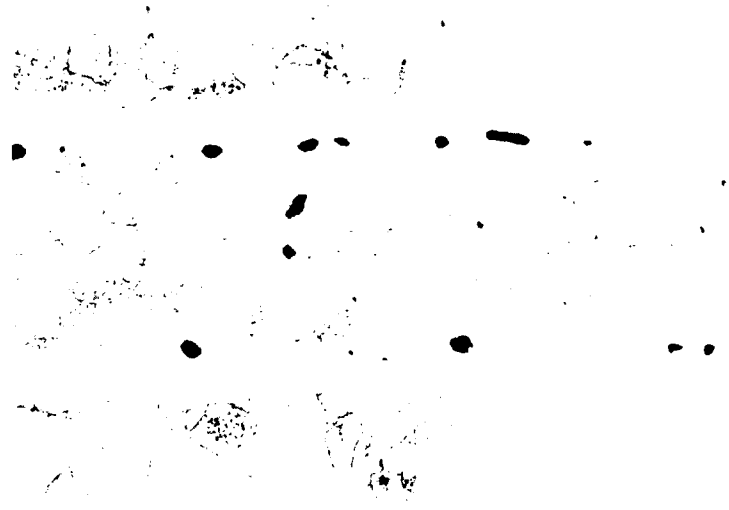

Figure 7a. 15-mil butt joint. 108/200/as brazed. (Kalling's etch, 100X.)*

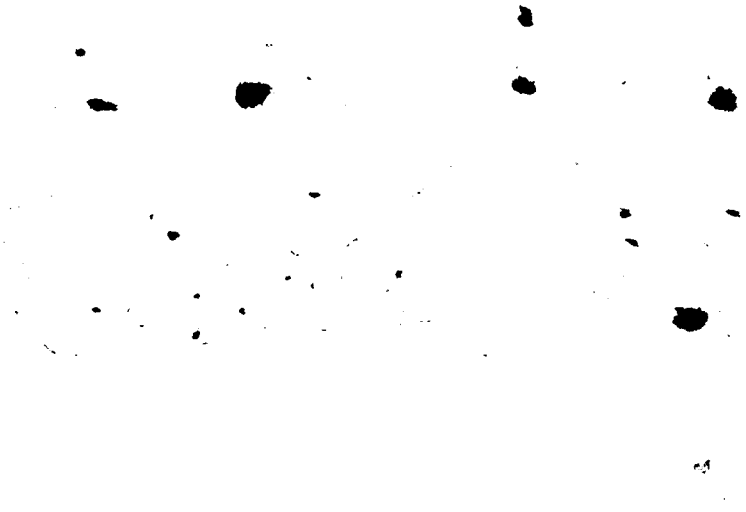

Figure 7b. 15-mil butt joint. 108/200/solution and aged. (Kalling's etch, 100X.)*

*Joint composition and condition code: Braze Sinter Metal/Braze Filler Metal/Metallurgical History

Figure 8a. [illegible]
(Fuller's etch, 100X).

Figure 8b. [illegible]
[illegible]

microstructural quality, Figures 9 through 12. All combinations are able to withstand the heat treatment without obvious deterious effects but also without appreciable homogenization. The joints which were made with René 80 as a sinter metal have a tendency to form layers of intermetallic particles at the joint interface. This condition is not significantly ameliorated by the heat treatment and seems to be least pronounced in the case of the as brazed 80/D-15 joint (see Figure 12a).

2.3.2.2.2 Conclusions

In view of the foregoing and a preference for not duplicating either the sinter metal or the filler metal in the two joint combinations, the following combinations are best:

1) Hastelloy C sinter metal with AMI DF-3 braze filler metal (Figure 9a), and

2) René 80 sinter metal with D-15 braze filler metal (Figure 12a).

These two types of joints will be evaluated for their physical properties and further characterized metallurgically in accord with the program plan.

2.3.2.3 Butt Joints from Coated Bars

In order to evaluate joint making with surfaces that had been coated, four tensile bar halves were Alpak coated. The coating was thermally diffused and grit blasted. The bars were then oxidized for 48 hrs. at 2100°F in air. Following oxidation, the coating was stripped from the bars, and the bars were fluorocarbon cleaned. Figure 13 shows a typical bar history.

After fluorocarbon cleaning, one 15-mil joint was made from each of the chosen sinter-filler metal

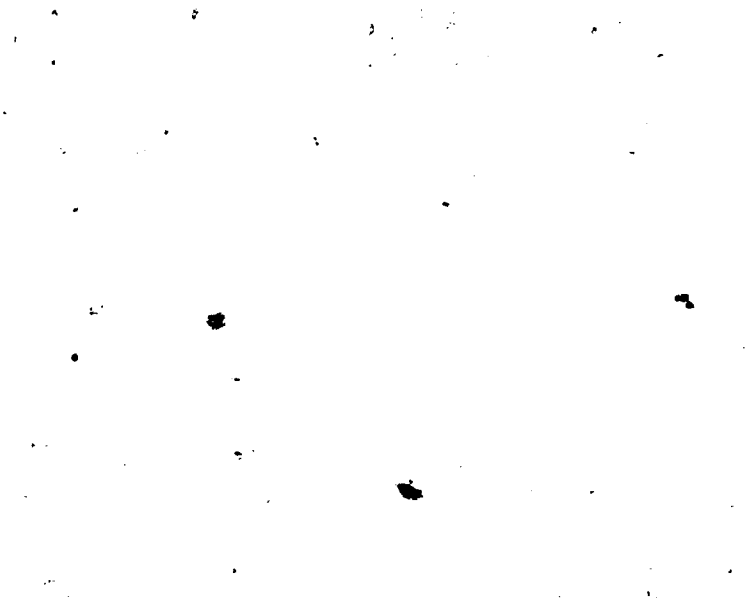

Figure 9a. 15-mil butt joint, C/DF-4/as brazed. (Kalling's etch, 100X.)

Figure 9b. 15-mil butt joint, C/DF-4/as brazed. (Kalling's etch, 100X.)

Figure 10a. 15-mil butt joint. C/D-15/as brazed. (Kalling's etch, 100X.)

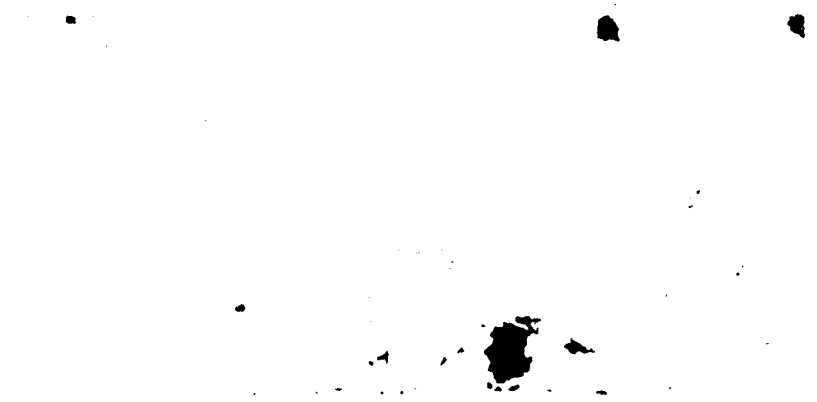

Figure 10b. 15-mil butt joint. C/D-15/solution and aged. (Kalling's etch, 100X.)

Figure 11a. 15-mil butt joint. 80/DF-3/as brazed. (Kalling's etch, 100X.)

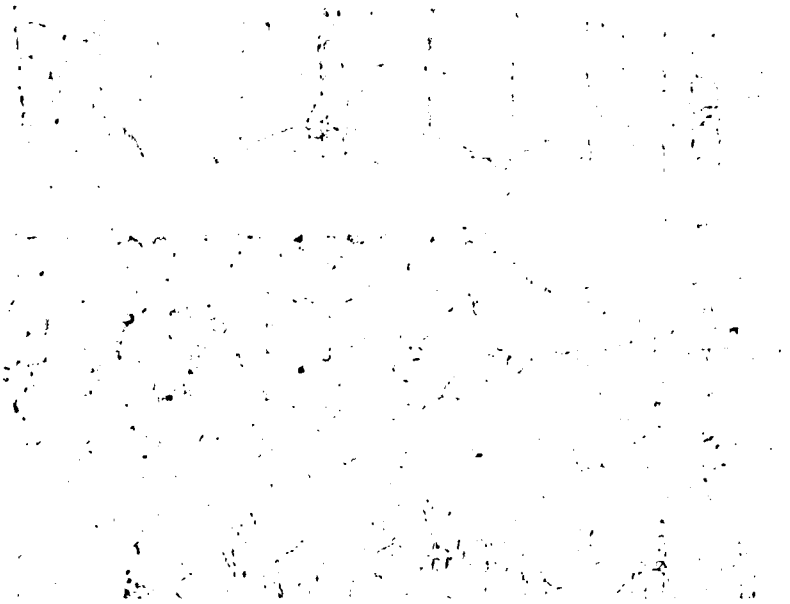

Figure 11b. 15-mil butt joint. 80/DF-3/solution and aged. (Kalling's etch, 100X.)

Figure 12a. 15-mil butt joint. 80/D-15/as brazed. (Kalling's etch, 100X.)

Figure 12b. 15-mil butt joint. 80/D-15/solution and aged. (Kalling's etch, 100X.)

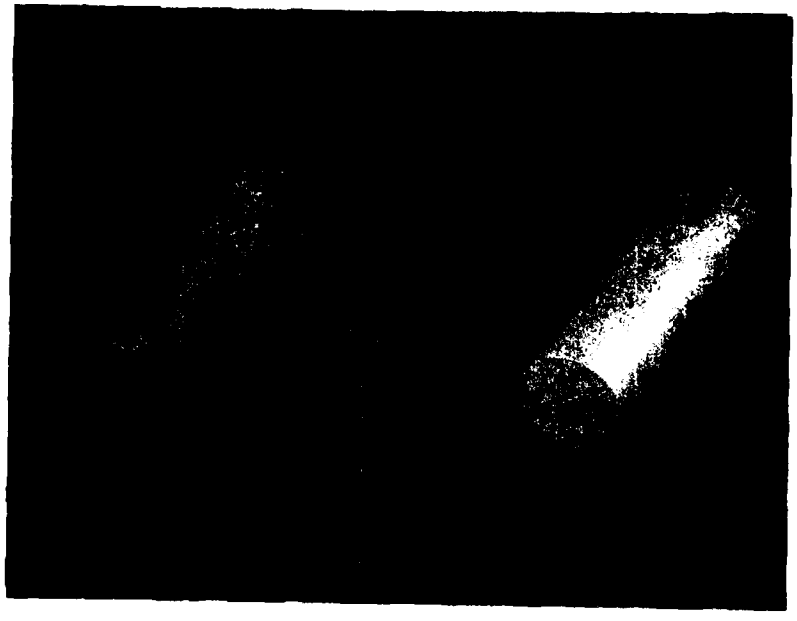

Figure 13. Bars for making of tensile bar joints. From left to right bars are Alpak coated, bar stripped of coating, and stripped and fluorocarbon cleaned respectively.

combinations. The joints were sectioned, heat treated, and metallographically prepared as before. The results of this effort may be seen in Figures 14 and 15; these should be compared to Figures 9 and 12 respectively. No significant difference is apparent.

It may thus be concluded that coated and stripped γ' alloys are as readily nickel brazed as are those which were never coated if both have been fluorocarbon cleaned. No further effort is planned with regard to brazing coated γ' alloys.

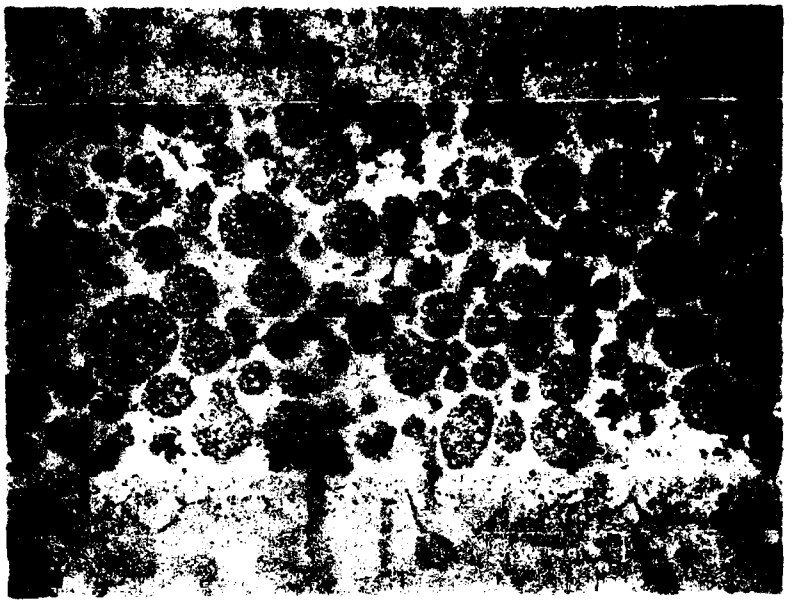

Figure 14a. Butt joint from stripped and fluorocarbon cleaned bars. Joint is C/DF-3/as brazed. (Kalling's etch, 100X.)

Figure 14b. Same as 14a but in the solution and aged condition.

Figure 15a. Butt joint from stripped and fluorocarbon cleaned bars. Joint is 80/D-15/as brazed. (Kalling's etch, 100X.)

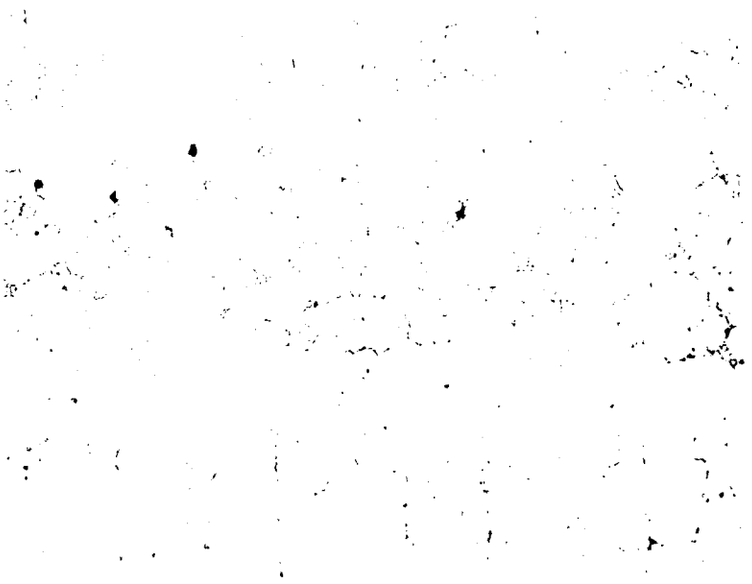

Figure 15b. Same as 15a but in the solution annealed condition.

SECTION 3

LIST OF REFERENCES

1. "Brazing of Hastelloy X with Wide Clearance Butt Joints," Technical Report AFML-TR-79-4026, March 1979.

2. "Engineering Properties of Alloy 713C," International Nickel Co., Inc., Nov. 1968, p. 6.

ADDENDUM 3

INTERIM TECHNICAL REPORT NO. 3

DEVELOPMENT AND EVALUATION OF WIDE GAP BRAZE JOINTS IN GAMMA PRIME ALLOYS

CONTRACT F33615-79-C-5033

INTERIM TECHNICAL REPORT

No. 3

31 January 1981

J. W. Chasteen

University of Dayton
Research Institute
Dayton, Ohio 45469

FOREWARD

This Interim Technical Report covers the work performed under Contract No. F33615-79-C-5033 during the period June 1, 1980 to January 1, 1981. It is published for information and the conclusions herein are those of the contractor alone.

This contract, with the Welding and Joining Group of the University of Dayton Research Institute, was initiated under the title "Development and Evaluation of Wide Gap Braze Joints in Gamma Prime Alloys." The work is being administered under the technical direction of Dr. G. E. Metzger of the Air Force Materials Laboratory, Metals and Ceramics Division, Wright-Patterson Air Force Base, Ohio.

The program is being directed by Dr. A. E. Ray, Project Supervisor, Metals and Ceramics Division. The principal investigator is Dr. J. W. Chasteen of the Welding and Joining Group.

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DAYTON, OHIO 45469

SECTION 1
INTRODUCTION

The first few turbine stages of advanced gas turbine engines must operate at temperatures which exceed the safe operating levels for stainless steels and solid solution superalloys. Engine components for these stages are often made from γ' hardened nickel base superalloys. Such components have become rather intricate in the air cooling techniques used and in their assembly (mechanical and brazed). Until recently, braze assembly of such components was marginal, and the technology for braze repair of such parts, upon retirement from service, was limited. The fluorocarbon cleaning process recently developed at UDRI now makes possible routine assembly and repair of γ' alloy engine components by standard nickel brazing techniques.

The physical properties of brazed joints and particularly wide clearance brazed joints have long been questionable. Consequently, welding is conventionally employed for assembly and repair of gas turbine engine components. Welding, however, has limitations in that it is a piece-by-piece, as opposed to a batch, operation and also it may not be possible to physically access the joint with a welding torch. In addition to these limitations, it is generally not possible to weld (or even braze) gamma prime type alloys by heretofore known art. As aforementioned, it has become possible to nickel braze gamma prime type alloys, even after service, if they are prepared by fluorocarbon cleaning prior to brazing. Since brazing is now available for such metallurgical systems and welding is still not an option, it is advisable to determine the physical properties of wide clearance nickel brazed joints in gamma prime alloys.

Such determinations are currently being conducted at UDRI under the auspices of USAF Contract No. F33615-79-C-5033, titled

"Development and Evaluation of Wide-Gap Braze Joints in [illegible]' Alloys." What follows is an interim report on the first phase of the subject effort.

SECTION 2
SYNOPSIS

In the making of wide clearance braze joints, it is not possible to use a braze filler metal alone; it will simply run out of the gap. The wide clearance joints of interest in this study are butt joints of 0.010 to 0.070 inches clearance and, in order to make them, a two step procedure is employed. The butt gap is first filled with the powder of a metal which has a high melting temperature relative to the braze filler metal with which it is to be combined. The joint is then partially sintered, i.e., the joint is heated until the joined bars can be handled, but the joint itself is porous. The powder that is used to form the porous joint is termed the "braze sinter metal." After the braze sinter metal has been sintered into place, it is brazed, i.e., the pores filled, with a braze filler metal which is compatible with both the braze sinter metal and the faying surfaces of the base metal.

The first phase of this program was devoted to the choice of sinter/filler combinations for making butt joints to evaluate. Three gamma prime type superalloys were considered as base metals. They were Alloy 713C, Inconel X-750, and Mar M 246. Four commercially available braze filler metals were screened for their compatibility with the base metals. The braze filler metals were BNi2, Nicrobraz 200, AMI DF-3, and D-15 alloy. All of the braze filler metals readily wet and run on all of the base metals when the base metals have been preoxidized and then cleaned by the Fluorocarbon Cleaning Process (FCP)[1]. Three commercially available braze sinter metal powders were chosen for evaluation by the sintered wafer technique[1]. Not all of the braze filler alloys were compatible with all of the braze sinter metals; this fact made it unnecessary to further evaluate some of the candidate sinter/filler combinations.

It was necessary to choose no more than two sinter/filler combinations for butt joint properties evaluations and the wafer evaluation technique is not totally conclusive, i.e., some combinations which result in a marginally brazed wafer will in turn produce a sound butt joint. Consequently, Alloy 713C bars were used to make brazed butt joints by use of the remaining sinter/filler combinations. The joints were subsequently sacrificed for metallographic investigations. At this point in the program, due to its wide use and in-house experience at UDRI, Alloy 713C was selected as the base metal material for all joints and tests to be made for the remainder of the program.

For various reasons (see Report No. 2)[2] the two sinter/filler combinations that were chosen for evaluations of physical properties of brazed, wide clearance butt joints were: (1) 140xD Hastelloy alloy C powder for braze sinter metal with the joint completed by brazing with AMI DF-3 braze filler metal and (2) -325 mesh René 80 powder braze sinter metal filled by D-15 alloy as a braze filler metal.

At this juncture, the base metal had been fixed as Alloy 713C and two sinter/filler combinations had been selected for making brazed, wide clearance butt joints. The program has now continued into the physical properties evaluations phases of the effort.

SECTION 3

TENSILE STRENGTHS OF WIDE CLEARANCE BRAZED BUTT JOINTS IN ALLOY 713C

Tensile strengths of all materials vary with temperature. In the case of brazed butt joints, one might also expect the tensile strength to be somehow dependent upon the width of the joint. The tensile test program of this effort has been designed to explore both dependencies and has the purpose of gaining a maximum amount of design information from relatively few tests.

3.1 THE TENSILE TEST BARS

The means and procedures for making tensile test specimen blanks has been previously reported[2]. The blanks are produced in such a manner that the brazed butt joint will appear in the middle of the tensile test span and have its fayed surfaces perpendicular to the direction of tension. The tensile test specimens and the stress rupture specimens (to be discussed later) were machined to ASTM standard blueprint E8 61T. A photograph of a typical specimen is shown in Figure 1. The butt joint is vaguely visible and is indicated by the arrow.

3.2 TENSILE STRENGTH VERSUS TEMPERATURE FOR A FIXED 15-MIL GAP

0.015-inch butt joints were made in twelve (12) tensile specimen blanks for each of the sinter/filler combinations (Hast. C/AMI DF-3 and René 80/D-15). The resulting tensile specimens were tested in duplicate at room temperature, 1000, 1200, 1400, 1600, and 1800°F. The tests were standard tensile tests that were conducted at a fixed crosshead speed of 0.05 in./min. The numeric results of these tests are listed in Tables 1 and 2; the results are listed in comparison to published base metal (alloy 713C) data[3]. Figure 2 graphically

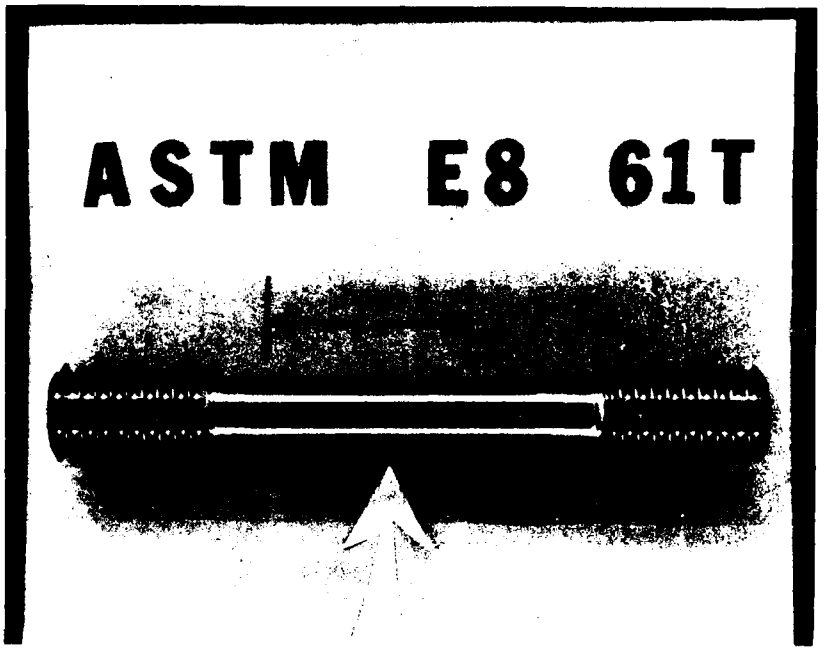

Figure 1. Typical Tensile or Stress Rupture Test Specimen. Arrow indicates brazed butt joint.

TABLE 1

TENSILE STRENGTH OF ALLOY 713C TEST BARS
WHICH HAD A 15 MIL BRAZED BUTT JOINT
IN THE CENTER OF THE TEST SECTION

Joint Material: -140 Hastelloy C sinter filler metal brazed with AMI DF-3

Sample* No.	Testing Temperature (°F)	Tensile Strength psi	Tensile Strength of Alloy 713C** (psi)
1	70	66,300	123,000
3		63,600	
4	1000	60,700	125,600
5		74,600	
6	1200	81,700	125,700
7		75,700	
8	1400	66,300	136,000
10		65,400	
11	1600	65,400	105,400
12		97,300	
14	1800	47,300	68,400
15		37,800+	

*Sample No. 2 was held for backup but was not needed; Sample No. 9 did not braze.

**See Reference 3.

+This failure appears to have initiated at a faying surface.

TABLE 2

TENSILE STRENGTH OF ALLOY 713C TEST BARS WHICH HAD A 15 MIL BRAZED BUTT JOINT IN THE CENTER OF THE TEST SECTION

Joint Material: -325 René 80 sinter filler metal brazed with braze alloy D-15

Sample* No.	Testing Temperature (°F)	Tensile Strength (psi)	Tensile Strength of Alloy 713C** (psi)
19	70	113,100	123,000
20		116,900	
22	1000	124,100	125,600
23		79,900+	
24	1200	126,000	125,700
25		122,200	
26	1400	122,900	136,000
27		116,500	
28	1600	110,300	105,400
29		130,500++	
31	1800	76,100	68,400
32		64,700++	

*Samples numbered 21 and 30 were used for stress rupture probe tests.

**See Reference 3.

+This sample had a single pore defect at the periphery of the test section.

++These samples failed in the base metal part of the test section.

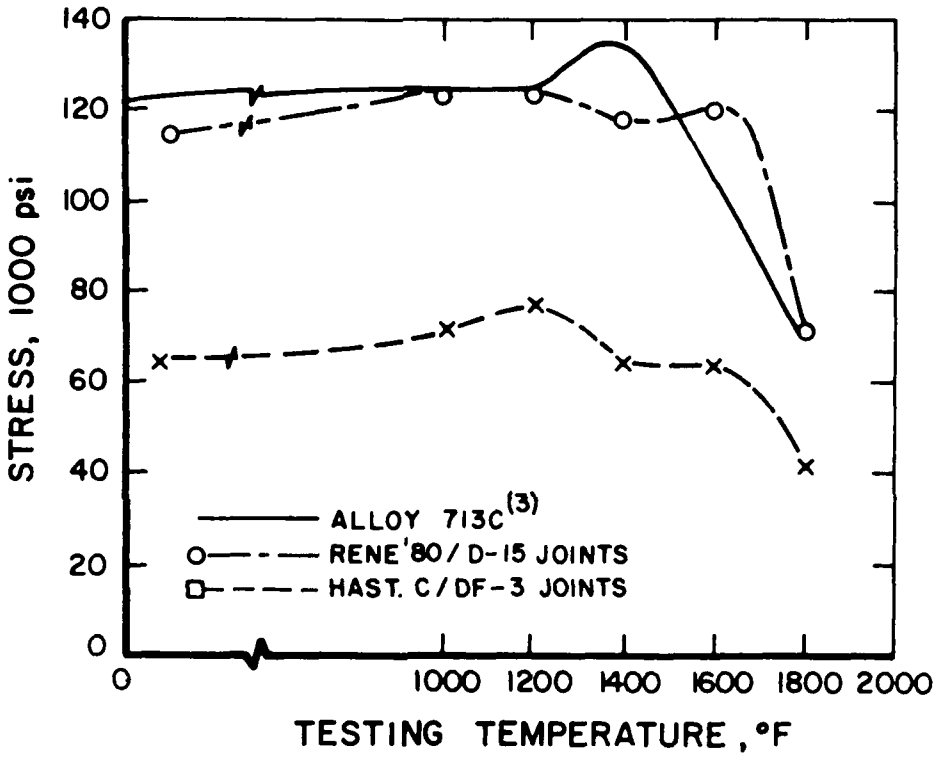

Figure 2. Tensile Strength Versus Temperature for 15-mil Butt Brazed Joints in Alloy 713C.

depicts the results and compares them to published properties of the base metal.

3.2.1 The Hastelloy C/AMI DF-3 Joints

There is nothing particularly noteworthy of the Hastelloy C/AMI DF-3 joints except that they performed surprisingly reproducibly. The joint strengths are on the order of 60% of that of the base metal. Although the joint strengths more favorably compete with the base metal at high temperatures, they never achieve high efficiencies. Figure 3 shows the strengths of the Hast. C/DF-3 joints in Alloy 713C compared to published[4] strengths for Hast. C/ Nicrobraz 200 joints in Hastelloy X. Since the brazed gaps are so wide, one would expect the influence of the base metal to be minimal. If this is the case, Figure 3 is an indication that, for a fixed braze sinter metal, physical properties of composite braze joints can be significantly affected by the choice of braze filler metal.

3.2.2 The René 80/D-15 Joints

Although the Hast. C/DF-3 joints suffer from comparative lack of strength, the René 80/D-15 joints have no such malady. Review of Table 2 and Figure 2 will support that, in all cases, the joint strengths were reasonably reproducible (except where there was an obvious defect) and that those strengths indicate a near 100% efficiency. Somewhat remarkable behavior is often observed at temperatures in excess of 1500°F, namely, the test bars often fail not in the joint at center span but in a less favorable portion of the test section in the base metal. This indicates that, at elevated temperatures, the René 80/D-15 wide clearance brazed joint is actually stronger than the Alloy 713C base metal. Photographs of the tensile bars that failed in the base metal, along with their duplicate specimens, are shown as Figures 4 and 5.

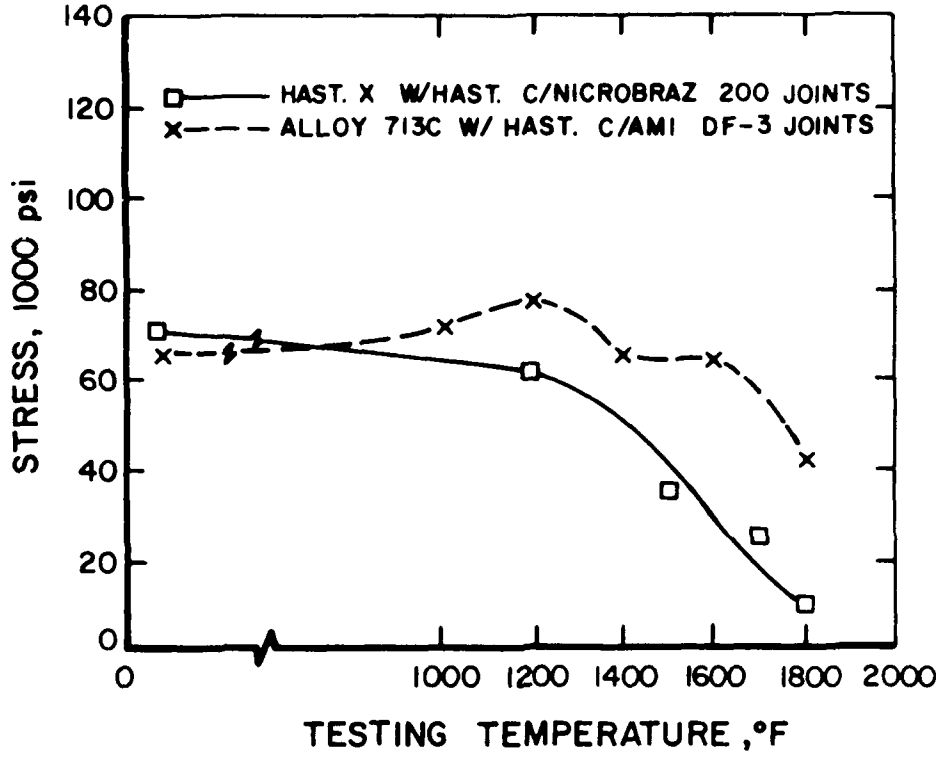

Figure 3. Comparison of Tensile Strengths Resulting from Different Braze Filler Metals for Varying Temperature.

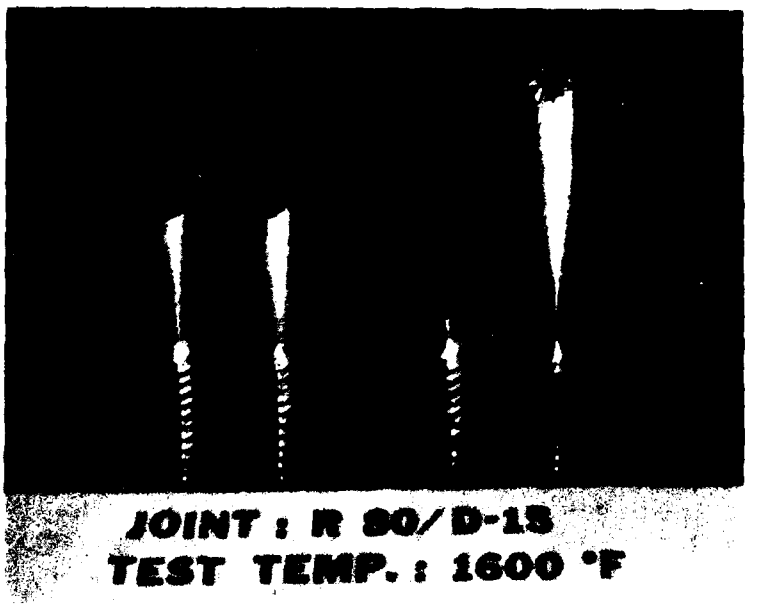

Figure 4. Fractures of René 80/D-15, 0.015 Inch Wide Butt Joints by Tensile Test at 1600°F.

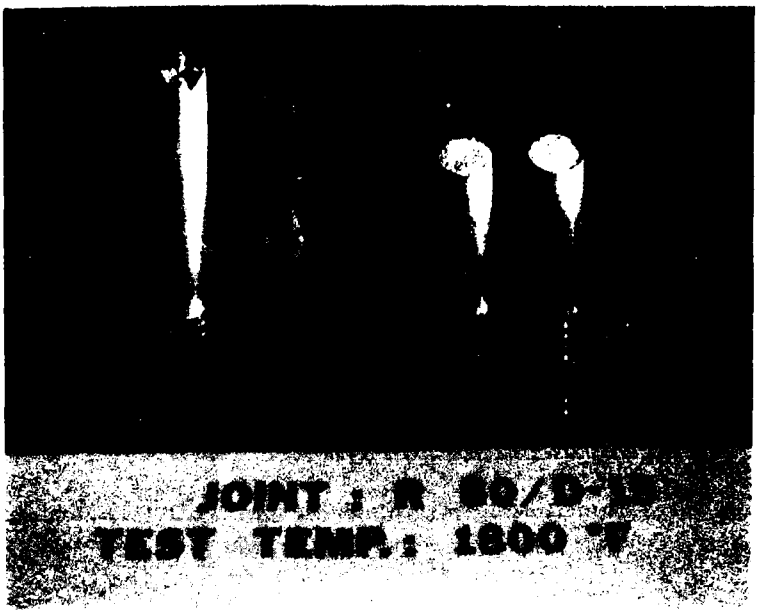

Figure 5. Fractures of René 80 (b-1y, 0.01[illegible] inch Wide Butt Joints by Tensile Test at [illegible]°F.

The results of the tensile tests indicate that it is possible to construct a wide clearance braze joint that is stronger than any chosen base metal. That is, it is always possible to achieve a 100% efficient braze joint. The attributes of the joint combination René 80/D-15 suggest many other joint making combinations. For example, any superalloy could be atomized to produce a braze sinter metal. Then a compatible braze filler metal could be produced by atomizing an alloy which was similar to the sinter metal but where most of the Al and Ti along with most of the high melting constituents such as Mo and W had been replaced by B, Si, and/or P. These observations in addition to the obvious promise of the René 80/D-15 joint prompted a decision to concentrate the remaining physical properties study on this joint alone.

3.2.3 Future Tensile Testing

In order to explore both the temperature effect and gap width effect on the tensile strengths of wide clearance brazed butt joints, a second tensile testing program is currently in progress. For this program, a series of brazed butt joints whose clearances range from 0.010 to 0.070-inches are being made by use of the René 80/D-15 sinter/filler combination. Joints with variations of 0.010-inches will be tested over the gap range. Joints will be tested in duplicate at both room temperature and at 1800°F.

The results of this program will be reported as part of the final report on the overall effort.

SECTION 4

STRESS RUPTURE LIVES OF WIDE CLEARANCE BRAZED BUTT JOINTS IN ALLOY 713C

The stress rupture behavior of wide clearance brazed joints is a necessary part of any design or repair criteria. Thus several bars have been subjected to such testing. Due to the encouraging results of the tensile tests the program has been limited to René 80/D-15 type joints of constant 0.015-inch clearances. Since the bars are brazed at 2200°F and furnace cooled, the base metal was adjudged likely to perform as though it had been solution treated. Published data for the base metal[3] indicates that the base metal rupture life at 1700°F and 30,000 psi stress should be approximately 121 hours. Eleven braze butt joined bars have been tested under these conditions; the results are listed in Table 3. The reviewer will quickly note the broad scatter in the rupture life data and that at least one test bar exceeded expectations.

The actual sequence of this test program has significance in the explanation of the results. Sample No. 30 was the first tested and its results prompted some excitement. Sample No. 21 was then tested with the intent of corroborating the results. The surprisingly short life of No. 21 caused the question of which result is typical. Sample No. 18 revealed a very short life and No. 16 was tested to ascertain whether a postbraze solution treatment was consequential. The results of these latter tests indicated that (1) postbraze heat treatment is not ameliorating and (2) some physical phenomenon was clouding the stress rupture results of the brazed butt joints.

At this point it became obvious that all of the joints except the long life joint had failed (to varying extents) at

TABLE 3

STRESS RUPTURE LIVES OF 15-MIL GAP BRAZED
BUTT JOINTS IN ALLOY 713C

Joint Combination: René 80/D-15

Test Conditions: 30,000 psi at 1700°F in air

Base Metal Life[3]: 121 hours

Sample No.	Rupture Life in hours	Post Braze Heat Treatment	Chronological Sequence
16	19.1	2150°F, 2 hrs., AC	3
18	5.0	none	4
21	10.0	none	2
30	124+	none	1
41	20.0	none	5
42	6.2	none	6
43	15.8	none	7
44	49.7	none	8
45	21.3	none	9
46	9.3	none	10
48	17.2	none	11

*Specimen No. 17 was solutioned and aged but not tested

**There are no specimens numbered 33 through 40

+This bar suffered from two furnace outages. Actual time to failure is untraceable, but it is known to have exceeded 124 hours.

one of the faying surfaces (see Section 5). Since samples 16 through 21 were from a single joint making batch, samples 19 and 20 were used in the tensile testing program (see Table 2), no further testing could be done on this group and the entire group was suspect. In order to resolve this dilemma another group of bars were very carefully made; all known procedural precautions were taken. The resulting specimens were numbered 41 through 50. Sample No. 49 was sacrificed for metallographic examinations and the remainder were subjected to stress rupture testing. The results to date are in Table 3. The remaining two bars (47 and 50) will be stress rupture tested at 1350°F and 90,000 psi.

The short life and wide scatter of these data are traceable to a varying density plane of pores at or near the upper faying surface.

SECTION 5

SOME CHARACTERISTICS OF THE BRAZED JOINTS AND THEIR FAILURES

Nominal microscopic and macroscopic investigations of the wide clearance brazed joints have been performed. The joint qualities are good by metallographic standards but the fracture surface morphologies are singular.

5.1 CHARACTERISTICS OF THE HAST. C/DF-3 JOINTS

5.1.1 Microscopic Observations

Figure 6 is a 100X photomicrograph of the Hast C/DF-3 15-mil joint (Sample No. 13). These joints are somewhat porous but not underly. The Hastelloy C particles show evidence of dissolving and the matrix metal seems to be nearly solid solution. The metallography of this joint is quite similar to that of the Hast. C/Nicrobraz 200 joint[4]. This joint has good metallurgical appearances but it cannot compete with the strength of the base metal (see Figure 2). Also despite the apparent similarities between this joint and that made with Nicrobraz 200 they display significantly different physical property behavior.

5.1.2 Macroscopic Observations

Figure 7 is a photograph of the matching halves of a tensile test failure of a Hast. C/DF-3 joint. The tensile failures were all similar; the one shown is from a room temperature test. It was selected on the basis of its brightness and detail clarity. Although it is not apparent from the photograph of Figure 7, the failure occurred through the middle of the joint and did not tend to favor or fail at a faying surface. The fracture is also irregular, i.e., there are no signs of pure planar failure. The physical properties of this joint would appear to represent the best possible performance of this sinter/filler combination, notwithstanding the possible effects of

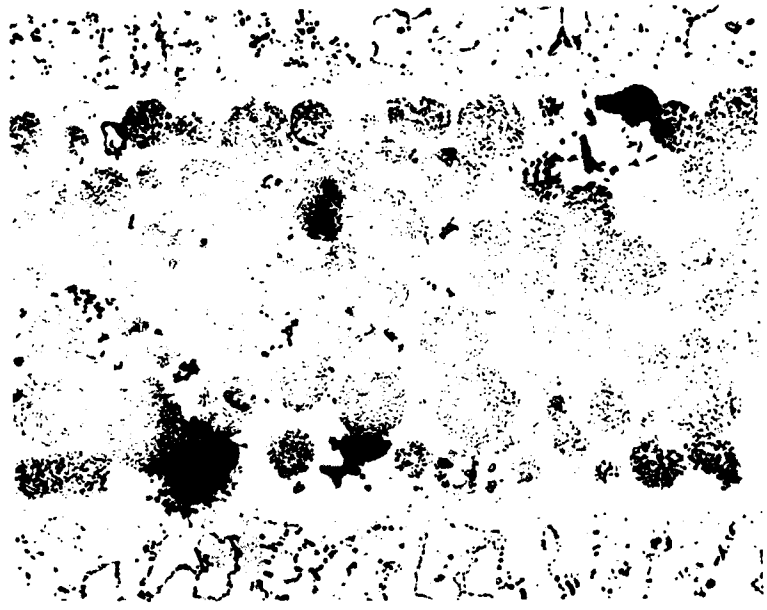

Figure 6. Typical Hast. C/DF-3 Joint. 100X Electro-etched at 4V for 10 sec. in sat. $K_2Cr_2O_7$.

Figure 7. Typical Fracture Surfaces from Tensile Failures of a Hast. C/DF-3 Brazed Butt Joint.

postbraze heat treatments. The lack of evidence of necking or fracture surface ductility though disconcerting is not unexpected.

The Hast. C/DF-3 joint is reliably reproducible but suffers from a serious strength deficiency. There is also no evidence of ductile behavior.

5.2 CHARACTERISTICS OF THE RENÉ 80/D-15 JOINTS

5.2.1 Microscopic Observations

Figure 8 is a 120X photomicrograph of a typical 15-mil René 80/D-15 brazed butt joint. The joint has an attractive metallurgical appearance in that it is nearly equiaxed and the filler metal seems to have bonded quite well with the faying surfaces. There is evidence of a brittle second phase (see light particles) but it is nearly homogeneously dispersed. This is quite unlike a simple braze joint where such particles tend to concentrate on the center plane of the joint and thus make it brittle. The joint of Figure 8, a first glance, appears good. The joint, however, has a serious deficiency in its porosity. The extent of the porosity is acceptable, but the reviewer may note that many of the pores tend to occupy a plane just inside the joint near the upper faying surface. The term "upper faying surface" not only refers to that orientation in Figure 8 but also to that orientation during the brazing cycle (see Figure 14). This plane of pores is apparently quite deleterious to long term, high temperature physical properties (see Section 4).

5.2.2 Macroscopic Observations

5.2.2.1 Tensile Failures

Figure 9 is a photograph of a typical tensile failure of a René 80/D-15, 15-mil brazed butt joint. The fracture surface displays some planar nature but is otherwise quite irregular. Since this behavior is typical one may

Figure 8. Typical René 80/D-15 Joint of 15-mil Clearance. 120X, Kallings etch.

JOINT

R 80/D-15

Figure 9. Typical Fracture Surfaces from Tensile Failures of a René 80/D-15 Brazed Butt Joint.

assert that the porous plane is considerably less influential in tensile testing than in stress rupture testing. The only accounting for such behavior is the short times, which would not allow for diffusion and agglomeration, and the high strain rates of the tensile tests. The author is not prepared to speculate on the outcome of tensile strengths, such as those in Table 2, if the tests were conducted at say 0.010-inches/min. rather than the 0.050-inches/min. that was used.

5.2.2.2 Stress Rupture Failures

Figure 10 is a photograph of the failed stress rupture specimen, Sample No. 30. This was the only one of eleven specimens that displayed a life that rivals the base metal (see Table 3). It is included in order to show the irregularity, i.e., nonplanar quality, of the fracture surface. It also demonstrates the kind of quality that such joints are capable of.

Figure 11 is a photograph of a more typical stress rupture failure surface (Sample No. 45). The fracture surface shown here is quite planar in nature and has the appearance of having been porous. That this failure tended to favor a faying surface may be noted in Figure 12. Figure 12 is a side view of the specimen of Figure 11 and shows that most of the joint material has clung to the right (bottom) half of the specimen. The bright ring on the left half was produced as wrench marks when the specimen was removed from the grips.

It seems clear, at this point that the René 8/D-15 joint is prone to the formation of a plane of pores near the faying surfaces which is last to be brazed. Furthermore, that plane of pores is a source of premature failure of the joint and, when such a plane does not exist, the stress rupture strength of a René 80/D-15 joint is competitive with that of the Alloy 713C base metal.

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DEVELOPMENT AND EVALUATION OF WIDE CLEARANCE BRAZE JOINTS IN GA--ETC(U)
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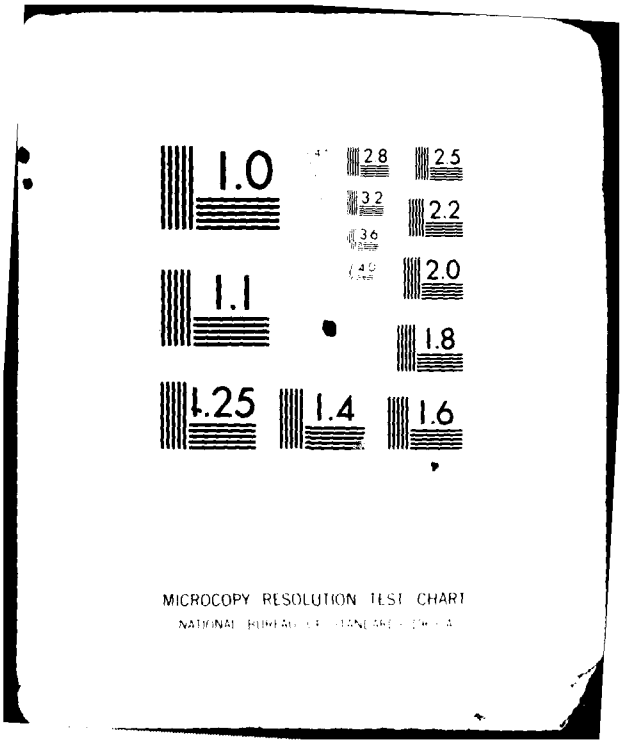

1.0
2.8
2.5
3.2
2.2
3.6
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART

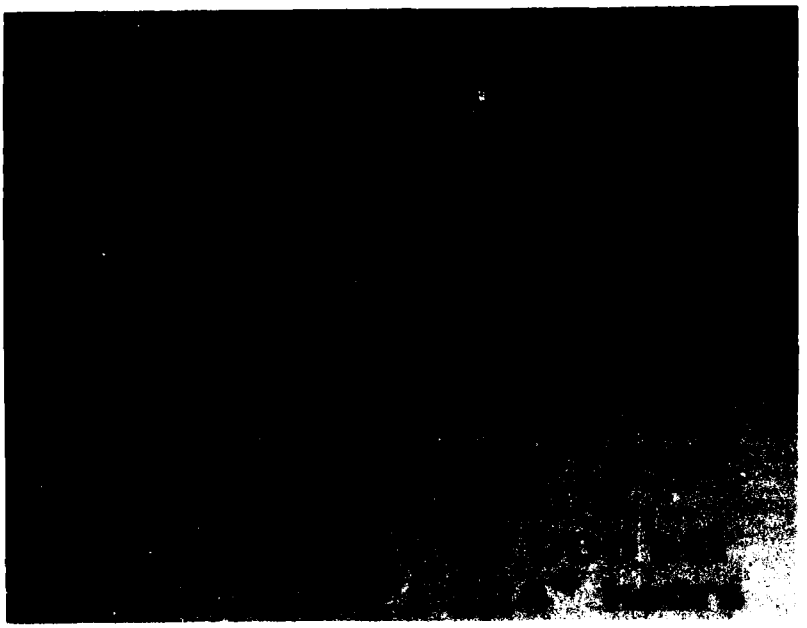


Figure 10. Fractured Stress Rupture Specimen Which Displayed Good Life. Photograph shows irregularity of the fracture surface.

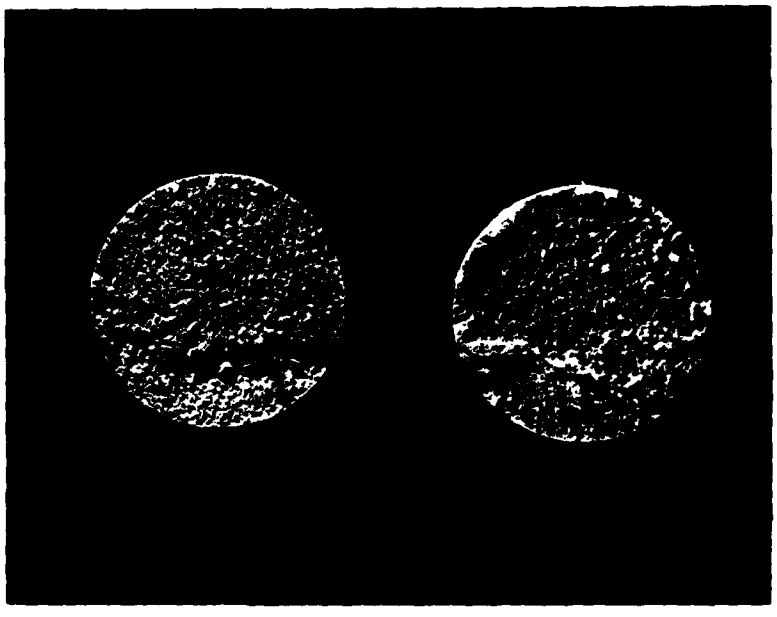


Figure 11. Typical Stress Rupture Fracture Surfaces from a René 80/D-15 15-mil Joint. Conditions: 1700° - 30,000 psi.

Figure 12. Side View of Figure 11 Specimen Showing Faying Surface Bias of the Fracture.

SECTION 6

THERMAL FATIGUE PROPERTIES OF WIDE CLEARANCE BRAZED BUTT JOINTS

A series of thermal fatigue tests is currently being conducted on the Duffer's "Gleeble" Model 510. The tests differ from the traditional alternate flame and air exposures of the edge of a wedge sample. This test is conducted by clamping a test specimen (Figure 13) in a rigid testing rig and then heating it by passage of electrical current in a temperature prescribed manner. The specimen is alternately allowed to cool. The test specimen was first used by Nippes[5] and is shown photographically in Figure 13. The test specimen blanks are presintered and brazed in a fixture (see Figures 14 and 15). This technique has been previously described (see Report No. 2)[2] and thus will not be further discussed.

Specimens having gap clearances from 10- to 70-mils will be tested in thermal fatigue and compared to the cycle life of base metal. The results of this effort along with a full elaboration of the procedure will be included in the final report.

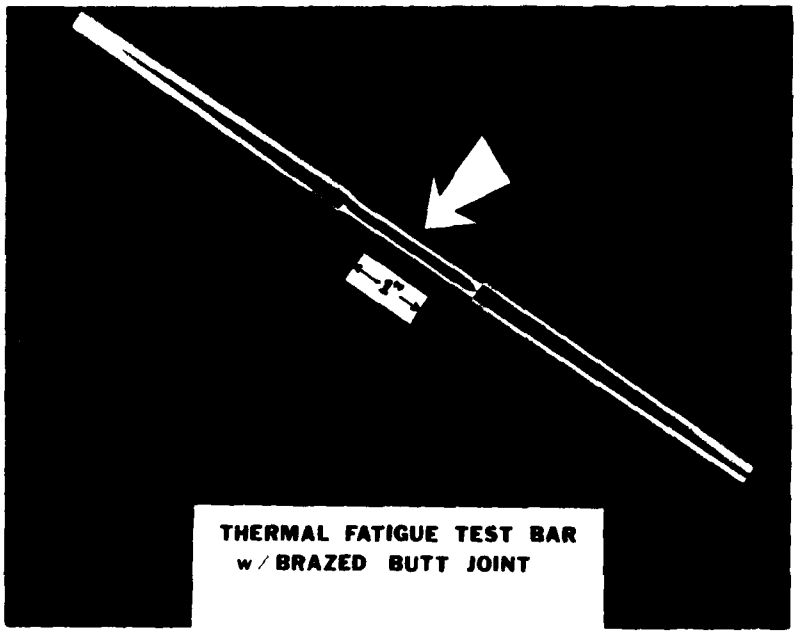


Figure 13. Typical Thermal Fatigue Test Bar.

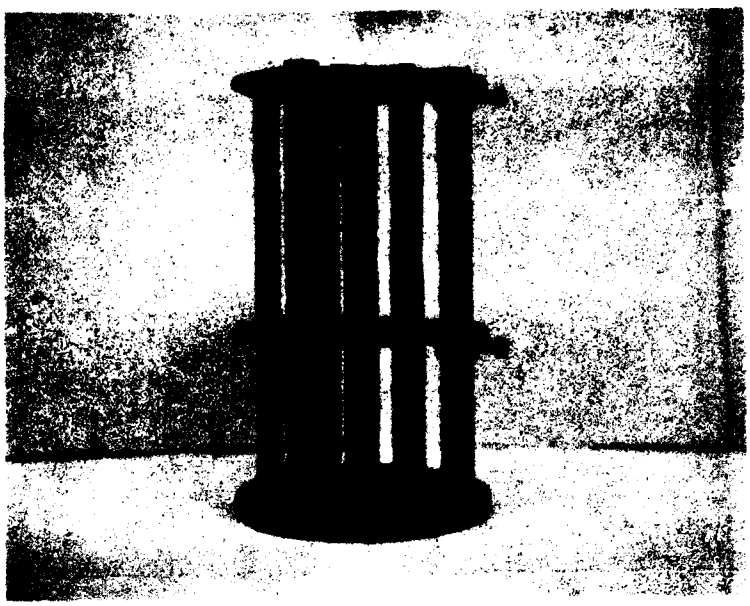


Figure 14. Fixture Assembly for Presintering the Thermal Fatigue Test Specimen Blanks.

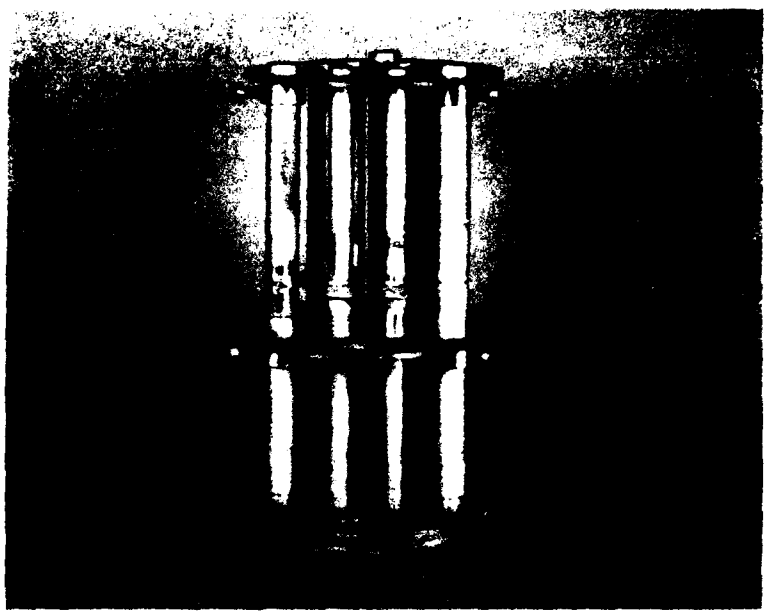


Figure 15. Fixture Assembly for Brazing the Thermal Fatigue Test Specimen Blanks.

SECTION 7
SUMMARY

The first portion of the physical properties testing phase of this program is complete. Tensile tests of bars which have a fixed 15-mil gap brazed butt joint at center span have shown the René 80/D-15 joint to have higher strength than the base metal, Alloy 713C, for temperatures in excess of 1500°F. Lower temperature strengths are comparable to the base metal. The Hast. C/DF-3 joint, though less prone to the formation of faying surface voids, has only about 60% of the base metal strength across the temperature spectrum.

Stress rupture tests were concentrated on the strong joint, i.e, René 80/D-15. These tests show wide scatter with some specimens being quite short lived. One bar, however, did perform much like what is expected of the base metal thus indicating the potential of the joint. The broad scatter and short lives have been tentatively traced to a plane of voids near the faying surface.

Tensile tests at fixed temperatures and varying gap widths as well as thermal fatigue tests are in progress.

REFERENCES

1. "Development and Evaluation of Wide Gap Braze Joints in Gamma Prime Alloys," Interim Technical Report No. 1, USAF Contract No. F33615-79-C-5033, 30 April 1980.

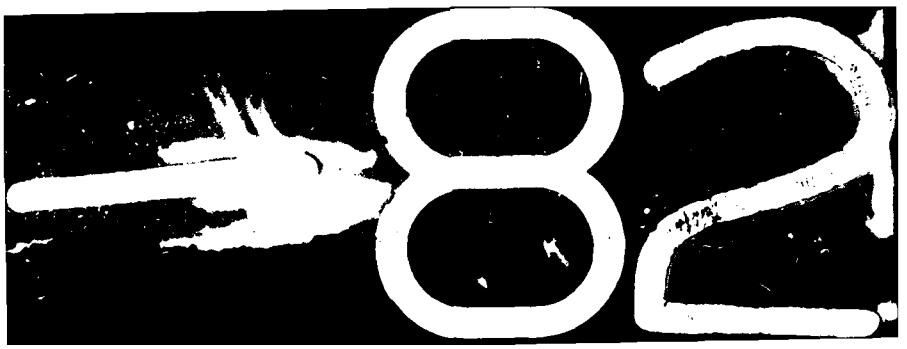
2. "Development and Evaluation of Wide Gap Braze Joints in Gamma Prime Alloys," Interim Technical Report No. 2, USAF Contract No. F33615-79-C-5033, 30 May 1980.

3. Engineering Properties of Alloy 713C, International Nickel Co., Inc., November 1968, p. 6.

4. J. W. Chasteen and G. E. Metzger, "Brazing of Hastelloy X with Wide Clearance Butt Joints," Welding Journal, 58, 4, April 1979.

5. E. F. Nippes and J. C. Uy, "A Method of Investigating Low Cycle Thermal Fatigue," Welding Journal, 46, 8, August 1967.

*U.S.Government Printing Office: 1982 — 559-006/5083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